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A COMPARISON OF THE VELOCITY OF VISUAL AND INFRA-RED LIGHT BY AN ASTRONOMICAL METHOD.*

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It is a well known fact that the velocity of light may be determined far more accurately by terrestrial than by astronomical methods. However this statement is probably no longer true if one wishes to compare the velocity of light in two different wave-lengths. The astronomical procedure is to determine the time of minimum light of an eclipsing variable star in two widely separated regions of the spectrum by photometric methods. The observed difference in the times of minimum light divided by the time it has taken the starlight to reach us gives the percentage difference in the velocity of light of the two spectral regions. Since the time of minimum can be observed to an accuracy of a few minutes and since it takes years for light from the nearest star to reach us, this method is one of great delicacy.

It is important to eliminate systematic errors from the observations which would tend to shift the true times of minimum in the two different spectral regions. I believe the method I have used is relatively free from such systematic errors. The observations contained in this memoir refer to

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the prototype eclipsing variable—Algol. All were made at the Sproul Observatory of Swarthmore College.

METHOD.

Spectra were formed by an objective grating. Since this grating was so constructed that the even order spectra are missing, it is possible to observe the first order infra-red without interference from the second order visual energy. A contact print of the spectra of Gamma Cassiopeia, shown in plate I, reveals the first and third orders. At the ends

PLATE I.

of the third orders the hydrogen emission line $H\alpha$ may be readily seen. Accurate measures of the position of this line indicate that the scale of the first order spectra is 483A/mm at the visual focus of the 24-inch telescope of the Sproul Observatory. In order to limit and measure the spectral region striking the photoelectric cell at any one time, a grating-spectrometer was used. This device also makes it possible to utilize the energy of both first orders. It is so constructed that the distance from the centers of the two slits to the central image may be readily adjusted and measured. A description of this device has already been published.[1]

In order to measure both the visual and infra-red energy of Algol a photoelectric photometer containing a Cs-O-Ag photoelectric cell was used. Numerous spectrophotoelectric observations have convinced me that its sensitivity to light of a given wave-length is not changed by exposure to light of other wave-lengths. The effective energy of Algol or its comparison star is much too small to produce fatigue effects. Since the sensitivity of the photometer changes slowly with the tilt of the telescope and with time, a standard light source was used to check this sensitivity. The current through this standard light source was carefully regulated.

In order to obtain ample effective energy from Algol at minimum light the two slits were 2.00 mm. or 966A wide. For

[1] *Ap. J.*, 84, 372, 1936.

the visual energy the centers of the slits were adjusted to correspond to 5500A and for infra-red their centers corresponded to 8660A. With the slits in these positions the effective infra-red energy averaged about 20 per cent. more than the effective visual energy of Algol.

It is generally admitted that 8000A is near the limit of visibility under optimum conditions. I quote Baly:[2] "The visible spectrum extends from about 7600 A.U. to about 3900 A.U."

The visual and infra-red energy of Algol was compared with that of Alpha Persei on 19 different nights from November 1935 to March 1937. Similar observations were also made on Oct. 14, 1937. The comparison star was observed on an average of three times on each of these 19 nights. Alpha Persei is classified as F5 and Algol as B8. The color of Algol however at maximum is near A2 and at primary minimum Fo. Data pertaining to each of these stars is given below.

Star.	Rt. Asc.	Decl.	Visual Magn.
			M
Alpha Persei	3^h $17^m.2$	49°.5	1.90
Algol	3 1.7	40.6	2.1 to 3.2

In general two readings in the visual followed by two readings in the infra-red constituted one observation of the variable for each spectral region. If Algol were not under constant observation check readings were always made in the visual. Many of the recent observations were made in the order—2 visual, 3 infra-red and 2 visual. The mean phase of the 4 visual and 3 infra-red readings is therefore the same for the observations made in this way. The standard light source was observed at about fifteen minute intervals. The visual and infra-red energy of Alpha Persei was compared with the response from the standard light source at longer intervals. Since this star was brighter than Algol more numerous readings were made on it whenever it was being observed. The background current was accurately observed at frequent

[2] *Spectroscopy*, 1, 23, 1929.

intervals throughout the course of all these observations. At primary minimum this was about 1/4 the total electrometer deflection due to Algol. Single readings required about a minute at this phase. An effort was made to keep the number of visual and infra-red observations of Algol as nearly the same and to make them at as nearly the same time as possible. This has undoubtedly helped to eliminate systematic errors.

Since the comparison star was about ten degrees from Algol it was necessary to make corrections for differential extinction. I have never observed this star when it was more than six hours off the meridian. At this hour angle for the latitude of Swarthmore its light transverses 2.4 atmospheres. When Algol and Alpha Persei were observed near the meridian the observations were corrected by using an extinction coefficient of $0^M.25$ for the visual and $0^M.10$ for the infra-red energy. When the two stars were observed at large hour angles, the extinction coefficients derived from repeated observations of the comparison star for each particular night were used. These coefficients average $0^M.22 \pm 0^M.04$ for the visual and $0^M.12 \pm 0^M.04$ for the infra-red energy.

The observed readings were corrected for background, change in sensitivity of the photometer and extinction. The infra-red and visual differences in magnitude in the sense Algol *minus* Alpha Persei are given in Table 1. The heliocentric Julian Day with 2,420,000 days already subtracted is given in parenthesis and corresponds to the heliocentric phase given directly below it. Zero heliocentric phase corresponds to minimum light (heliocentric J.D. 2428113.5689) and is given in fractions of the period; the assumed period is 2.86731077 days.

The observations of October 14, 1937, were alternated with observations of the comparison star. Since these are also more numerous than those made previously they are given double weight in the discussion. The minimum seemed to occur five minutes earlier than that predicted on this night and 0.0012 was added to all computed phases for the discussion of these data. The phases given for these observations in Table 1 have not been so corrected.

TABLE I.*

Visual and Infra-red Observations.

(Helioc J.D.) Helioc Phase	Δm 5500A	Helioc Phase	Δm 8660A	(Helioc J.D.) Helioc Phase	Δm 5500A	Helioc Phase	Δm 8660A
(8113.5078)a	M		M	*(8182.4713)*	M		M
.9787	1.04	0.9794	1.50	.0303	.77	0.0303	1.32
.9884	1.33	.9871	1.63	.0320	.76	.0320	1.31
.0351	.81	.0346	1.34	.0397	.66	.0397	1.21
(8116.4952)b				*(8193.5239)*			
.0206	1.09	.0201	1.57	.8850	.37	.9218	.93
.0264	.93	.0260	1.47	.9226	.40	.9295	.91
.0286	.92	.0291	1.44	.9287	.38	.9331	.95
.0351	.79	.0354	1.39	.9301	.39	.9348	.95
.0361	.81	.0434	1.25	.9323	.39	.9379	.96
.0429	.67	.0458	1.23	.9338	.42	.9418	1.05
.0465	.63			.9360	.45	.9459	1.05
(8127.7013)b				.9394	.48	.9469	1.05
.9288	.36	.9274	.98	.9408	.48	.9508	1.10
.9319	.45	.9307	.98	.9430	.48		
.9384	.44	.9350	1.02	.9452	.57		
.9522	.59	.9391	1.02	.9483	.56		
		.9474	1.19	.9505	.61		
		.9536	1.16	*(8196.6463)*			
		.9619	1.34	.9740	1.07	.9744	1.62
(8136.4515)				.9783	1.13	.9775	1.64
.9805	1.06	.9807	1.59	.9800	1.14	.9806	1.62
.9832	1.15	.9825	1.63	.9875	1.29	.9864	1.72
.9907	1.31	.9900	1.75	.9885	1.33	.9913	1.74
.9982	1.45	.9965	1.84	.9936	1.38	.9948	1.77
.0001	1.45	.0009	1.85	.9955	1.45	.9962	1.79
.0040	1.42	.0023	1.87	.9969	1.44	.9976	1.77
.0069	1.35	.0050	1.84	.9981	1.42	.9988	1.80
.0151	1.18	.0074	1.80	.9993	1.42	.0000	1.78
.0171	1.12	.0166	1.63	.0007	1.47	.0012	1.79
(8173.5409)b				.0019	1.42	.0036	1.69
.9189	.36	.9106	.93	.0031	1.39		
.9233	.43	.9179	.93	.0043	1.33		
.9262	.38	.9235	.97	*(8199.5222)*			
.9284	.35	.9257	.92	.9770	1.11	.9782	1.57
.9313	.37	.9291	.89	.9789	1.10	.9845	1.65
.9352	.37	.9308	.91	.9837	1.29	.9879	1.61
.9364	.37	.9320	.90	.9849	1.20	.9937	1.80
.9386	.43	.9339	.95	.9871	1.25	.9956	1.75
.9415	.42	.9375	.95	.9888	1.29	.9968	1.75
.9432	.49	.9397	.99	.9932	1.37	.9980	1.75
.9463	.48	.9407	.99	.9963	1.38	.9990	1.78
.9526	.65	.9436	1.02	.9973	1.40	.0002	1.77
.9567	.77	.9455	1.04	.9985	1.41	.0014	1.77
		.9520	1.16	.9997	1.41	.0027	1.77
		.9554	1.21	.0007	1.41	.0039	1.78
				.0019	1.41	.0051	1.78

TABLE I (*Continued*).

(Helioc J.D.) Helioc Phase	Δm 5500A	Helioc Phase	Δm 8660A
(8199.5222)	M		M
.0033	1.42	.0073	1.73
.0045	1.43	.0097	1.73
.0057	1.43	.0155	1.63
.0067	1.35		
.0079	1.42		
.0091	1.39		
.0144	1.30		
.0161	1.23		
(8612.5314)*ae*			
.0176	1.16	.0183	1.60
.0188	1.12	.0190	1.61
.0204	1.10	.0212	1.57
.0234	1.01	.0231	1.56
.0243	.97	.0248	1.50
.0257	.94	.0253	1.47
.0279	.91	.0280	1.41
.0340	.71	.0346	1.33
.0358	.69	.0360	1.28
.0368	.67	.0371	1.27
.0385	.63	.0378	1.26
(8615.5037)*e*			
.0542	.58	.0543	1.12
.0555	.49	.0550	1.08
.0560	.46	.0564	1.04
.0581	.45	.0578	1.04
.0584	.45	.0588	1.03
.0597	.41	.0595	1.01
.0638	.36	.0640	.97
.0652	.38	.0650	1.01
.0666	.38	.0672	.99
.0676	.34	.0674	.98
.0696	.30	.0698	.97

(Helioc J.D.) Helioc Phase	Δm 5500A	Δm 8660A
(8497.6604)*b*		
.9553	.56	1.02
.9609	.54	1.08
.9674	.80	1.28
.9766	1.06	1.50
.9797	1.17	1.52
.9845	1.27	1.67
.9867	1.27	1.73
.9906	1.34	1.69
(8500.5535)*gb*		
.9643	.75	1.34
.9682	.75	1.34
.9709	.81	1.39
(8500.5535)*gb*	M	M
.9765	.99	1.50
.9845	1.33	1.77
(8503.5601)*c*		
.0129	1.27	1.60
.0158	1.21	1.59
.0187	1.23	1.64
.0223	1.06	1.55
.0259	.96	1.47
.0290	.84	1.36
.0360	.81	1.38
.0425	.64	1.21
.0459	.68	1.19
.0498	.59	1.14
.0556	.49	1.04
.0578	.44	.98
(8517.6682)*d*		
.9332	.37	.95
.9388	.57	1.15
.9501	.52	1.16
.9552	.57	1.15
.9606	.79	1.36
.9686	.94	1.52
(8529.5070)		
.0621	.46	.98
(8566.5472)*g*		
.9802	1.07	1.55
.9826	1.08	1.57
.9953	1.32	1.78
.9980	1.45	1.86
.0125	1.32	1.73
.0200	1.22	1.64
(8589.5412)		
.9997	1.40	1.83
.0036	1.37	1.74
.0058	1.37	1.79
.0123	1.34	1.80
(8592.5104)		
.0351	.83	1.36
.0375	.79	1.29
.0397	.77	1.30
.0419	.71	1.25
.0479	.57	1.18
.0537	.51	1.09
.0593	.45	.99

TABLE I (*Continued*).

(Heliocentric J.D.) Heliocentric Phase	Δm 5500A	Δm 8660A		(Heliocentric J.D.) Heliocentric Phase	Δm 5500A	Δm 8660A	
(*8821.6590*)	M	M		(*8821.6590*)	M	M	
.9527	.638	1.189		.9828	1.253	1.662	
.9598	.762	1.290		.9996	1.430	1.800	
.9628	.806	1.357		.0231	1.102	1.592	
.9659	.886	1.392		.0270	.998	1.486	
.9698	.963	1.440		.0304	.889	1.390	
.9731	1.001	1.529		.0341	.809	1.312	
.9765	1.064	1.564		.0396	.670	1.238	
.9795	1.108	1.597		.0435	.602	1.172	

* The meaning of the various symbols given in Table I is as follows:

a Observations interrupted by clouds.

b Observations stopped by clouds.

c Observations stopped by moonlight on grating.

d Uniformly hazy. Magnitude differences interpolated according to time.

e Observed extinction coefficients used.

g Trouble checking standard lamp due to temporary instability of galvanometer.

DISCUSSION

Nordmann made visual observations of Algol through blue and red liquid filters on six different nights in 1908.[3] On the basis of his data he concludes that the red minimum (6800A) precedes the blue minimum (4500A) by 13 minutes and estimates the accuracy of this interval as 3 minutes. I believe he overestimated the accuracy of his data.

Maggini[4] found that the red minimum (6450A) preceded the blue minimum (4120A) by 17 minutes. Although Maggini's observations appear consistent it is very difficult to judge their accuracy since he neglected to mention atmospheric extinction and does not publish his data in detail. Stebbins[5] has found strong observational evidence that the components of Algol are ellipsoidal. With reference to Maggini's observations he says: "However, he (Maggini) did not find any variation of light between minimum, and from his published data I am unable to determine how it was that the star was measured with no apparent change between eclipses."

[3] *Bull. Astron.*, **26**, 21, 1909.

[4] *Bull. Astron.*, **35**, 131, 1918.

[5] *Ap. J.*, **53**, 106, 1921.

I regard Hnatek's[6] spectrophotometric observations of Algol to be of negligible weight. He has only four points on one side of the minimum and his curves through the data have been drawn in a highly arbitrary manner.

Mustel[7] has observed Algol on one night with the two different filters. He makes no mention of atmospheric extinction despite the fact that his observations were started when Algol was more than seven hours off the meridian.

The last of the five observers, Skoberla,[8] was apparently the first to give due consideration to the possibility of systematic errors. He is the only one of the five who states that he has corrected his observations for differential extinction. His visual observations indicated that the blue (5120A) minimum preceded the red (5990A) minimum by 11 minutes. This is in the opposite sense to the differences found by Nordmann and Maggini. Skoberla claims that the probable error of this interval is four minutes. However, since he only observed Algol on two nights, I believe he has also overestimated the accuracy of his data.

The evidence indicated by these observations of Algol is therefore conflicting. These apparent shifts in the epoch of minimum light for the various wave-lengths have been ascribed to various causes; observational errors, dispersion of light in interstellar space, and to a lack of symmetry in the stellar atmospheres.

Neglect of differential atmospheric extinction seems to be the most obvious source of observational error which is probably present in the data of four of these observers. This is particularly important in the case of Algol since there are no nearby comparison stars of similar magnitude. It is also more important in the regions of shorter wave-lengths since the atmospheric extinction changes much more rapidly with the wave-length in the blue than in the red or infra-red regions. If mid-eclipse occurs when both the variable and the comparison star are on the meridian, this effect has no influence in the determination of the epoch of minimum light. Such an ideal case is highly improbable. It is easy to show that if the minimum occurs when Algol is five hours off the

[6] *A. N.*, **184**, 305, 1910.
[7] *A. J. Soviet Union*, **11**, 514, 1934.
[8] *Zs. f. Ap.*, **12**, 1, 1935.

meridian, the minimum in the blue may be displaced from that in the red by several minutes due to neglect of differential extinction. The direction and amount of this apparent displacement depends on the choice of comparison stars and at what hour angle the observer starts or stops observing. This statement is true for any of the usual comparison stars.

Russell, Fowler and Borton,[9] and others have found that matter in interstellar space is far too scarce to account for any observable shift in the times of minima of different wave-lengths. The same reasoning is also true for matter in the earth's atmosphere.

Since the components of Algol are ellipsoidal it is probable that the period of rotation of the primary is the same as that of the period of revolution of the system. Kurt Walter says:[10] "Bezüglich der Rotationdauer der Komponenten kann man nur bei der stark elliptischen Komponente ohne weiteres auf eine Übereinstimmung zwischen Umlaufszeit in der Bahn und Umdrehungsdauer schliessen." In the case of Algol Struve and Elvey [11] have found strong spectroscopic evidence that the periods of rotation and revolution are the same. It is therefore highly improbable that the observed displacements of minima are due to any lack of symmetry of the stars. Since the period of the third body is nearly two years its mean distance from the primary is relatively great and should therefore exert no measurable influence on the relative times of minimum light in different wave-lengths

My own observations of primary minimum (with the exception of October 14, 1937) were arranged according to phase and normals were formed containing two successive observations. The observations of October 14 were all given the phase correction mentioned in a previous section, and are plotted together with these normals in Fig. 1. The two curves drawn through the data are symmetrical with respect to a central line through zero phase.

The method of computing the times of primary minimum and its probable error for each of these wave-length regions was suggested to me by Dr. Schilt and is as follows.

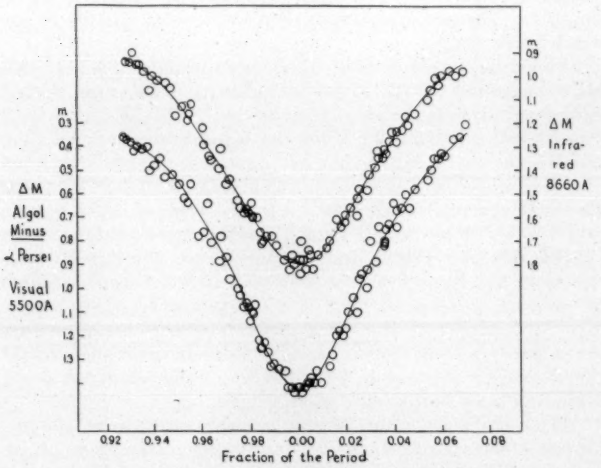
[9] *Ap. J.*, **45**, 337, 1917.

[10] *Universiläts-Sternwarte Königsberg*, Heft **81**, 1931.

[11] *M. N.*, **91**, 663, 1931.

It was first assumed that the minimum of one curve is at phase P_0. Magnitude residuals, observed minus curve, were recorded and weighted according to the numerical slope of the curve. Let the sum of their squares (pvv) be denoted by S_2. A similar summation was then computed after the same curve had been shifted to $P_0 + 0.002$ and S_3 was found. The curve was next shifted to $P_0 - 0.002$ and S_1 was determined. If

FIG. 1.



Light curve of primary minimum of Algol in different wave-lengths.

we assume that the sum of the squares of the residuals is a quadratic function of the phase, the true minimum is at

$$P_0 = 0.002 \frac{S_1 - S_3}{2(S_1 + S_3 - 2S_2)},$$

and if the mean error is the phase shift for which S is double its minimum value then the mean error is given by:

$$\pm\, 0.002 \sqrt{\frac{8S_2(S_1 + S_3 - 2S_2) - (S_1 - S_3)^2}{4(S_1 + S_3 - 2S_2)^2}}.$$

The phase of primary minimum and its mean error were computed in this manner for each curve. These computations showed that the infra-red minimum preceded the visual by about 20 seconds. Since the computed times of minima depend somewhat on the shapes of the curves drawn through the data, the size and even the sense of this figure could be changed in this arbitrary manner.

The probable error of the determination of the time of minimum for each wave-length region is about 6 minutes, and therefore the probable difference in the times of minima is eight minutes. This latter figure should be the probable difference if the observations were made entirely independent of one another, for example, if the visual and infra-red observations were made at different observatories. However, the manner in which these observations were made was such that the errors occurring in one wave-length band are not independent of those in the other. The error in the *difference* in the times of minimum is therefore less than eight minutes.

A good example of this reasoning is to be found in the observations of October 14, 1937. After adding 0.0012 to all phases we find that the nine observations well distributed on the descending branch of each curve follow the mean curves very nicely, and the six observations after primary minimum differ systematically from the mean curves. Since the infra-red readings were sandwiched between the visual ones on this night, their phases are the same. Let us now read the phase of each mean curve on its descending branch corresponding to each of the six observed magnitude differences of the ascending branch. The midpoint between each phase on the descending branch so determined and the corresponding phase of the observation on the other branch is a determination of the phase of primary minimum, and is given for each wave-length region in Table 2.

It is evident from these data that a systematic error has crept into the observations. Since it is evidently present in the observations in both spectral regions, the systematic difference in the two phases of primary minimum is small, 0.00025 or very nearly a minute. The probable error of this difference predicted from the errors at the bottom of the first two columns is 0.00044 as compared with the value 0.00018 derived

from the observed differences in the third column. Although these data are not sufficiently numerous to place much reliance on the errors as given, nevertheless they do illustrate the advantage of making the observations practically at the same time when attacking this particular problem.

I believe that my observations of Algol show that the visual (5500A) and infra-red (8660A) times of minimum occur simultaneously with an uncertainty of not more than three minutes.

Skoberla [12] has recently discussed data pertaining to the Nordmann-Tikhoff effect or the alleged phenomenon whereby the time of minimum light is a function of the wave-length. He has collected the results of studies of the times of minimum

TABLE 2.

Phase of Primary Minimum
(Obs. of Oct. 14, 1937).

5500A	8660A	Diff.
0.0015	0.0017	0.0002
.0011	.0006	−.0005
.0003	−.0005	−.0008
.0002	−.0008	−.0010
−.0010	−.0007	.0003
−.0015	−.0012	.0003
Mean .00010	−.00015	−.00025
p.e. ±.00032	±.00030	±.00018

All figures given without signs are positive.

of 35 eclipsing stars in different wave-length regions. Subsequent papers by such experienced observers as Huffer,[13] Hellerich,[14] and Walter [15] relating to W U Ma, RZ Cass, U Cep and U Sag as well as the data presented in this paper all give strong indication that for these stars this effect, if it exists, is masked by the errors of observation. However, the results tabulated by Skoberla with the possible exception of RZ Cass indicate that the red minimum for each of the above stars precedes the blue by several times the errors of these more recent and more accurate observations.

[12] *Zs. f. Ap.*, 11, 36, 1935.
[13] *Ap. J.*, 79, 370, 1934.
[14] *A. N.*, **256**, 405, 1935; *A. N.*, **261**, 120, 1937.
[15] *Zs. f. Ap.*, 16, 167, 1938.

The so-called Nordmann-Tikhoff phenomenon by its very nature can never be proven not to exist. But it is interesting to note that as observational accuracy increases the effect seems to decrease in about the same proportion.

Dr. Schlesinger's General Catalogue of Stellar Parallaxes gives $0''.031 \pm 0''.004$ as the trigonometric parallax of Algol. This corresponds to 32 parsecs or 105 light years with a probable error of 13 per cent. In 105 years there are 55 million minutes. My observations show therefore that there is an even chance that visual rays travel with the same velocity as infra-red rays to within an accuracy of about three parts in 55 million. This corresponds to 16 meters per second. Since Michelson, Pease and Pearson [16] have found unexplained systematic discrepancies amounting to several kilometers per second in their determinations of the velocity of light, it is evident that the method I have used to compare the visual with the infra-red velocity of light is a very critical one.

I am very grateful to Dr. John A. Miller then director of the Sproul Observatory for his enthusiastic support of this program. I also wish to thank Mr. R. W. Delaplaine for his valuable assistance in recording the data and checking the computations. Grants from the American Philosophical Society and the Joanna Wharton Lippincott Fund of Swarthmore College have enabled me to make most of the observations given in this paper.

[16] *Ap. J.*, **82**, 26, 1935.

Population Peak—1960.—That the population of the United States probably will not reach its crest until about 1960 is the opinion of Dr. O. E. Baker, agricultural economist of the Department of Agriculture. The number of births per year, however, has been downward since 1924. Births per year have declined from nearly 3,000,000 in 1921 to about 2,300,000 in recent years, Dr. Baker points out. He cites figures to show that enrollment in the first grade of public schools has declined about 100,000 each year since 1930. Enrollment in elementary schools as a whole is declining, and there are about 12 percent fewer children under 10 years of age in the nation than when the census was taken 9 years ago.

R. H. O.

Power of Soil Creep Shown in Stone Line.—A " stone line " in a stream or gully bank or in a road or railroad cut is often a puzzle to observers who see a more or less definite arrangement of angular stones lying nearly on the level or at a slight slope and with nothing to show their origin. Soil scientists explain the stone line as one of the interesting evidences of how soils are made and of how they move under natural conditions as contrasted with unnatural erosion common after man has interfered. A stone line, says H. A. Ireland of the Soil Conservation Service, is usually made up of fragments of a resistant layer of rock in the original parent material. As the main body of the rock weathered, these remained. Later "soil creep" developed. Soil creep is the gradual but resistless downhill movement of the main soil mass which may be so slow as to be imperceptible or may be evident within a lifetime. Soil creep exerts enormous pressure and breaks off fragment of the resistant rock masses which it carries along. Continuing for centuries perhaps, the soil creeps downward. One fragment of rock follows its predecessor to form a stone line which comes to light across the face of a cut through the soil layers. In some soils and on steep slopes the evidence of soil creep may leave obvious signs such as poles and fence posts tilted by the pressure of the moving soil mass, rock walls displaced, and trees tilted until the trunks grow curved.

R. H. O.

A FOUR-YEAR RECORD OF ULTRAVIOLET ENERGY IN DAYLIGHT.

BY

MATTHEW LUCKIESH, A. H. TAYLOR AND G. P. KERR,

Lighting Research Laboratory, General Electric Company, Nela Park, Cleveland.

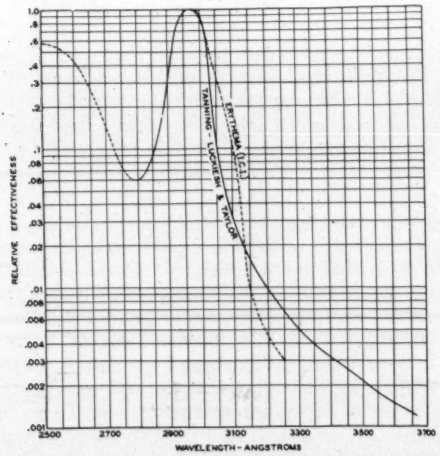
About two years ago the authors reported [1] the results of a study of the ultraviolet energy in daylight for a two-year period. This study has been continued since that time and we are now able to summarize the results for four complete years. The apparatus and test methods were fully described in the previous paper, hence they will be only briefly reviewed.

The ultraviolet energy was measured by a cadmium-magnesium alloy phototube [2] sensitive only to energy of wave-lengths shorter than approximately λ3350. Its spectral sensitivity is such that it responds to the ultraviolet energy of various wave-lengths approximately in accordance with their effectiveness in producing erythema or sunburn. It was mounted on the roof of a building on the outskirts of Cleveland in a region fairly free from dust and smoke. The phototube was mounted with the opening horizontal so as to measure the energy incident on a horizontal plane, and was connected to an electronic integrator indoors.

One of the obvious effects of ultraviolet energy in daylight is the production of erythema (sunburn) and tan. These effects are produced principally by ultraviolet energy in the spectral region measured by the phototube used in our measurements. We have recently published results pertaining to the relative effectiveness of different spectral regions in the production of tan.[3] In Fig. 1 are shown the results obtained, as well as the erythemal effectiveness curve adopted sometime ago by the International Commission on Illumination. In Fig. 2 are presented the spectral distribution of the ultraviolet energy in sunlight at noon on a clear day in midsummer, and its spectral effectiveness in the production of tan. A monthly summary for the four-year period of the ultraviolet in daylight

incident on a horizontal plane is shown in Fig. 3. The unit of energy used is one *E-viton* per square centimeter. This is equivalent to 10 microwatts of energy per square centimeter at λ2967, where the relative erythemal effectiveness is 1.0, or 10/E microwatts at any wave-length having an erythemal effectiveness E (see Fig. 1). To produce a minimum perceptible erythema (MPE) or barely perceptible reddening of an

FIG. 1.



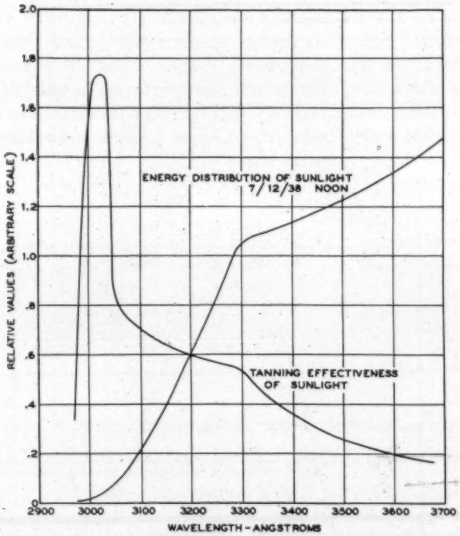
Relative spectral effectiveness of radiant energy in the production of erythema (as adopted several years ago by the International Commission on Illumination) and tan (Luckiesh and Taylor).

average untanned skin requires an exposure of approximately 40 *E-viton minutes per square centimeter* of skin. Thus an MPE would be produced by any one of the following exposures:

1 E-viton per square centimeter, acting for 40 minutes
10 E-vitons per square centimeter, acting for 4 minutes
40 E-vitons per square centimeter, acting for 1 minute.

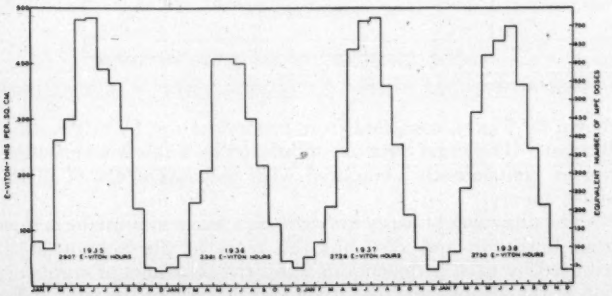
We use this unit because it is so closely related to the biological reaction, sunburn, with which all are familiar.

FIG. 2.



Relative energy distribution of direct sunlight at noon on July 12, 1938, and the relative tanning effectiveness of this sunlight.

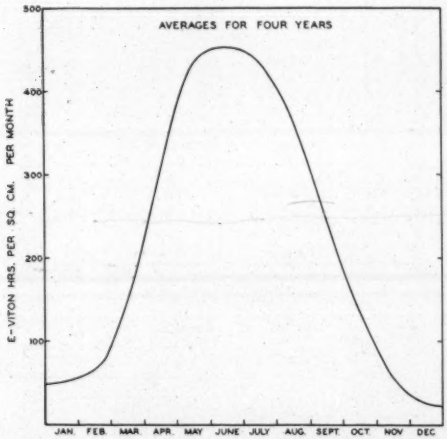
FIG. 3.



The monthly variation of erythemal ultraviolet energy in daylight on a horizontal plane for four consecutive years.

In Fig. 4 and Table I are presented the *average* monthly variations of the ultraviolet energy in daylight for the four-year period. Since sunlight reaches the earth through a greater layer of atmosphere in winter than in summer and since the days are also much shorter, the total ultraviolet energy is greatly reduced in winter. In this latitude, which is in the "cloud belt" near the Great Lakes, a further factor tending to reduce the ultraviolet energy is the great amount of cloudiness during the fall and winter. This factor is clearly

FIG. 4.

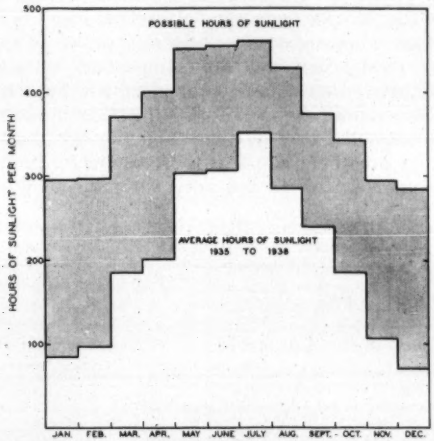


The average monthly variation of erythemal ultraviolet energy in daylight for the four-year period.

shown by Fig. 5, compiled from reports of the U. S. Weather Bureau. The same data are tabulated in Table I where they can be conveniently compared with measurements of ultraviolet energy.

The ultraviolet energy incident on a horizontal plane comes from both sun and sky, but the ratio of the amount contributed by each is dependent upon the clearness or composition of the atmosphere and upon the altitude of the sun. We have determined the ratio for many clear days during the

FIG. 5.



For Cleveland, Ohio, the number of *possible* hours of sunlight per month (upper curve) and the actual *average* hours of sunlight per month (lower curve) averaged for four years. The shaded area indicates the number of hours the sun was obscured by clouds.

TABLE I.

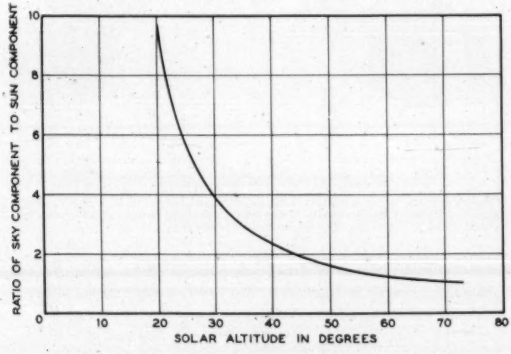
Variation of Average Hours of Actual Sunshine per Month and of Erythemal Ultraviolet Energy in Daylight as Measured on a Horizontal Plane for a Period of Four Years, 1935–1938, in a Suburb of Cleveland, Ohio.

Month	Hours of Sunshine			Erythemal Ultraviolet Energy	
	Possible	Average	Per Cent. of Possible	*E-viton Hours per sq. cm.	Per Cent. of Total for Year
Jan.	295	84	28	51	1.9
Feb.	297	97	33	65	2.4
Mar.	370	185	50	182	6.8
Apr.	401	201	50	265	9.8
May	452	303	67	432	16.1
June	455	304	67	452	16.8
July	461	352	76	435	16.2
Aug.	429	285	66	346	12.9
Sept.	374	239	64	250	9.3
Oct.	343	185	54	130	4.8
Nov.	295	106	36	53	2.0
Dec.	285	71	25	27	1.0

* An exposure of approximately two-thirds of an E-viton hour per sq. cm. will produce an MPE.

year, always with a clear sky, and the *average* results are presented in Fig. 6. The maximum altitude reached by the sun in Cleveland is approximately 73 degrees, under which conditions the *average* sun and sky components of erythemal ultraviolet energy on a horizontal plane are approximately equal. Sometimes near noon during the midsummer months, the sun component exceeds that from the sky, but on the *average* they are about equal at those times. This fact was generally unknown or ignored until our previous study and

FIG. 6.



Ratio of sky to sun component of the erythemal ultraviolet energy on a horizontal plane as affected by solar altitude.

undoubtedly accounts for the experience of many in receiving a surprising sunburn when exposed only to the sky.

Some additional interesting facts disclosed by this research are as follows:

On the average, the total ultraviolet energy in daylight (weighted erythemally) for the month of June is approximately 9 times as much as in January and 17 times as much as in December.

Approximately 80 per cent. of the total erythemal ultraviolet energy for the year is received in the six-month period from April to September, inclusive.

Only 7 per cent. of the year's supply of erythemal ultraviolet energy is received in the four-month period from November to February, inclusive.

The highest intensity of ultraviolet energy from the viewpoint of erythemal effectiveness, as measured during the four-year period, was approximately 4.2 E-vitons per square centimeter. This will produce an MPE on *average* untanned skin in about 10 minutes.

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The Time Ambiguity.—A. A. MERRILL. A part of the mental confusion endemic on this earth and due to the use of words with multiple meanings showed itself recently in science. The trouble was due to a double meaning given to the word TIME. Long before there was any science, as now understood, all animals lived a phenomenon properly called TIME, which phenomenon creates (1) a knowledge of the difference between "before" and "after" and (2) experience plus memory. When science was born it desired to measure everything quantitatively but TIME as above defined can not be measured quantitatively. So science did the best it could, which was this. It picked out some particular MOTION, treated it as "privileged," called it a clock and took the length in space passed over by that MOTION as its "t" unit.

It is a strange thing but the most common phenomenon in all reality, namely MOTION, has no symbol in physics. There is a symbol for the length in space passed over by a MOTION (L) and a symbol for the ratio between two such lengths (V) but MOTION as a reality has no symbol. Early in history the "t" of physics was represented by a length in space measured linearly, the MOTION being of sand or water falling downward but these clocks were a bother and so humans invented clocks with circular dials, an idea suggested of course by the revolution of the stars about the earth, but in every case to get a number for a "t" unit, you must measure some length in space. Properly speaking $V = L/L$, but to avoid confusion the denominator is changed to "t," but it is not TIME and a failure to see this truth will account for a lot of the nonsense that has been written on relativity. People repeatedly say: "He aged greatly during the past year." Now "aged greatly" refers to TIME, but "the past year" refers to a displacement of matter in space, which is not the same thing at all.

RADIO IN NAVIGATION.

BY

C. D. TUSKA,

Patent Department, Radio Corporation of America

INTRODUCTION.

"Radio in Navigation" is a treatise. It has three main divisions: first, the historical aspects of radio direction and position finding; second, the technical characteristics of directional radio; and third, the practical application of radio in navigation. The rapid growth of radio as a navigational instrument will be described by pointing to some of the most important developments. The events of lesser importance will be omitted lest they detract from the description as a whole.

A brief preliminary statement of the technical factors of the subject will be helpful: Radio waves are propagated in straight lines. The wave front is normal to the line of propagation. The direction of wave travel may be indicated by detecting the wave front. This indication lacks "sense"; i.e., it does not show whether the waves are approaching or receding. "Sense" can be determined, and thus the true bearing of the source discovered. In the foregoing system the transmitter has an omnidirectional characteristic; the receiver has a uni- or bidirectional response.

In another system a directive transmitter and a non-directive receiver are used. The transmitter is arranged to radiate a beam of radio frequency energy. The beam is rotated at a known rate. The receiver indicates the maximum beam signal as the beam sweeps by the receiver. The maximum response occurs when the beam points directly from the transmitter to the receiver. Thus the bearing of the receiver with respect to the transmitter may be obtained. The beam may be fixed to establish a definite radio course. Most radio aids to navigation are based upon either of the above systems.

EARLY HISTORY.

About fifty years ago Heinrich Hertz wrote: "Wir haben also nunmehr ein Mittel, die Richtung der electrischen Kraft in jedem Punkte zu erkennen." * [1] Hertz had created electric oscillations, had established experimentally that the oscillations were accompanied by electromagnetic waves, and had determined the direction of the waves.[2] Inasmuch as the waves could not be detected outside of his lecture room, which was 14 meters by 12 meters, it is probable that even Hertz's able imagination did not picture the application of electromagnetic waves to navigation.

Not quite a decade after the classic experiments of Hertz, Marconi offered a practical system of wireless telegraphy of limited range.[3] S. G. Brown [4] proposed to increase the transmission and reception range by employing pairs of antennas. The antennas were spaced by a distance of one-half the operating wave length. The electromotive forces induced in the receiving antennas had a phase relationship which depended upon the angle between the wave front and the line through the antennas and the distance between them. Thus directive effects were first produced. A similar system was described by Stone,[5] who offered a complete theory and described in detail the directive characteristic of the array.

Marconi [6, 7] investigated the directive properties of antennas which had a long horizontal element and a short vertical conductor. He found the aerial was most directive in the horizontal direction opposite the free end. His patents [8, 9] describe an array comprising a number of horizontal aerials radiating from a central point. The aerial leads are connected through a selective switch to a receiver or transmitter to indicate the direction of reception or to transmit a maximum signal along a predetermined line. It is quite probable that none of these early experimenters truly conceived of his device as a real aid in navigation.

TECHNICAL CHARACTERISTICS OF DIRECTIONAL RADIO.

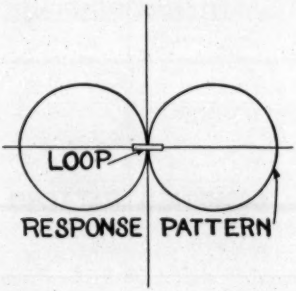
The directive characteristic of a shielded radio receiver is a function of its antenna. One of the simplest of directive

* Thus we now have a means of discerning the direction of the electric force at every point.

antennas is called a loop. It consists of one or more turns of conductor. The terminals of the loop are connected to a variable tuning capacitor so that the antenna may be tuned to the frequency of the waves to be detected. The terminals are also connected to a radio receiver which includes a suitable signal indicator. The loop is rotatably mounted so that its plane may be oriented with respect to the radio wave fronts to be indicated. The axis of rotation is generally parallel to the electric field of the waves.

When the plane of a loop antenna is parallel to the front of a vertically polarized radio wave, the magnetic lines of force of the wave induce equal electromotive forces in the

FIG. 1.

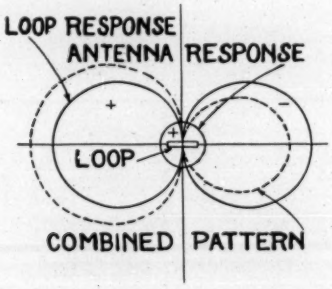


vertical conductors of the loop. The currents created by these forces are equal and opposite in the loop circuit; therefore, no circulating currents flow in the loop. When the plane is normal to the wave, the number of magnetic lines intercepted by the vertical conductors are no longer equal and opposite; unequal electromotive forces are created; and circulating currents are established in the loop. The electromotive forces are proportional to the sine of the angle between the loop plane and the wave front.[10] Therefore, the polar response pattern will be a figure-of-eight as shown in Fig. 1.

Since the response changes very gradually at the maximum and most rapidly at the minimum, radio bearings are usually observed at the loop minimum. If the loop is symmetrical

with respect to its axis of rotation, and if the associated circuits are symmetrical with respect to the loop and ground, the effects of the stray capacities from oppositely polarized elements to ground will neutralize. When the loop and associated circuits are not symmetrical, the capacities to ground will be unbalanced. The loop will act, through these unbalanced capacities, as a non-directive antenna. This is known as the "antenna effect";[11] it broadens the minimum and tends to make the response asymmetrical as shown in Fig. 2. If the phasal relations are other than shown, the

FIG. 2.



minimum becomes broader. Both the broadened minimum and the asymmetrical pattern deleteriously affect the radio bearings. It is customary to shield the loop to reduce its capacity to ground, and to exercise precautions to maintain symmetry.

A loop receiver may exhibit the desired directional characteristics, when it is tested at a point remote from objects which tend to effect its response, but upon installation in an airplane or a ship the nearby metallic structures alter the response pattern.[11, 12, 13, 14, 15] These effects have been explained by assuming that the nearby metallic objects absorb energy from the waves and reradiate such energy. The reradiated energy is received by the loop along with the directly radiated energy. Since the directly and indirectly received energies establish currents of different phase, the

minimum obtained by rotating the loop is not an indication of the true bearing. These reradiation effects are usually observed at 90° intervals and are called quadrant errors. Errors due to reradiation may vary with frequency. Numerous methods of correction have been proposed: for example, a correction scale,[16] an automatically compensated scale,[17] a neutralization by compensation loops,[18, 19] screens [20] or antennas.[21, 22]

Because of the low signal response of a loop, before the advent of suitable radio frequency amplifiers, it was customary to make the loop area large (5) * to increase the signal pick-up. A large loop cannot be rotated easily and quickly. Bellini & Tosi † proposed a system [23] which avoided these difficulties. A pair of large vertical loops are erected so that their planes intersect at right angles. The terminals of the loops are connected to the fixed coils of a radio goniometer. The goniometer usually consists of three coils: Two of the coils are fixed and their planes are at right angles; an exploring coil is rotatably mounted within the fixed coils. The exploring coil is connected to a radio receiver. A bearing scale is associated with the exploring coil.

The operation of the system may be explained as follows: The radio waves induce in the loops electromotive forces which are proportional to the sine of the angles between the loop planes and the wave fronts. The electromotive forces cause currents to flow through the fixed goniometer coils, and thus establish, within the coils, a resultant local magnetic field. The orientation of the local field corresponds to the original magnetic field. The local field may be explored by the rotatable goniometer coil. The rotatable exploring coil has a response pattern which would be obtained if the coil were used as a loop antenna. The goniometer system with its fixed loops is subject to all of the errors (19), (20), (21) of a rotatable loop antenna. An additional error may be present if the goniometer is not symmetrical.

In the period prior to 1908 in the operation of either the loop or the goniometer, the operator first tuned the receiver

* Reference numeral in parentheses indicates prevous citation.

† Artom claims to have been prior to Bellini & Tosi. See Artom's British Patents 23488 of 1903 and 19805A of 1906.

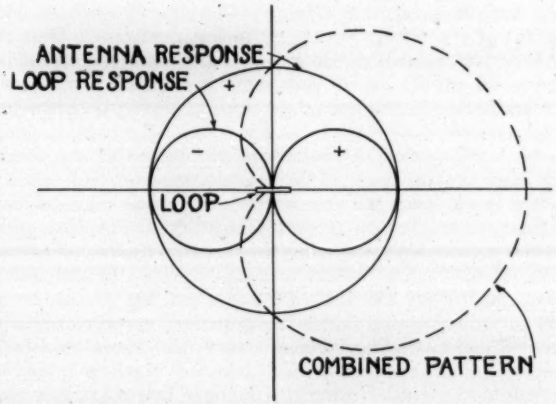
to a radio transmitter of known frequency and known location. The loop or exploring coil was generally rotated to a maximum response for this purpose. After adjusting the receiver, the movable coil or loop was rotated until a null was obtained. Some operators listened for faint signals on "either side" of the null and averaged the readings to measure the bearing more accurately. It will be observed that a figure-of-eight response pattern presents two nulls. If the pattern is symmetrical, the nulls are displaced 180°. If the operator had no further information, he merely knew that the directive receiving antenna was parallel to the wave front and that the antenna was located presumably on a line normal to the wave front and passing through the source of the waves. There was no reliable method for indicating whether the transmitter was on one side or the other side of the loop. In many cases the operator knew the approximate receiver location and therefore could resolve the ambiguity. For example, radio bearings on a land station taken by an operator on a ship on the high seas, might have been reasonably assumed to indicate that the ship was on the sea side of the land station. Such assumption would be very dangerous during war times when decoy stations could be in operation.

The ambiguity of radio bearings was corrected by making the response pattern unidirectional instead of bidirectional. About 1908 Bellini and Tosi [24] proposed to couple to the goniometer type of receiver a non-directive receiving aerial. The non-directive aerial is adjusted so that its response is equal to the response of one of the directive antennas. If the response of the directive antennas is represented by a figure-of-eight, and the non-directive antenna response by a circle as shown in Fig. 3, and if the antennas are suitably phased, the combined response will be indicated by the dash line. The dash line is a cardioid or special case of the Limaçon of Pascal. If the non-directive antenna response r_2 in polar coördinates is $r_2 = 1$ and the directive antenna response $r_1 = \sin \phi$ and if $r_1 = r_2$, the combined response $r = r_1 \pm r_2 = 1 \pm \sin \phi$, where ϕ = angle between plane of the directive antenna and the wave front.

A similar cardioid response pattern may be had by employing a loop receiver and a non-directive antenna.[25]

The loop may serve both directive and non-directive functions.[25] The response pattern will be a cardioid as shown in Fig. 3. Dr. G. W. Pickard in his article in the Proceedings of the Institute of Radio Engineers, Vol. 8, No. 5—October 1920, states that credit for the cardioid response patterns is incorrectly given to Bellini and Tosi and he refers to his patent.[25] With either the Bellini and Tosi or Pickard Systems, the unidirectional characteristic makes it possible to indicate "sense" by the maximum of the response and the exact bearing by either the null of the directive antenna or

FIG. 3.



the null of the combined antenna patterns. Thus twenty years after Hertz's famous experiments the means for obtaining radio bearings were available. In 1904 De Forest [26] states: ". . . I have been able to locate with certainty a transmitting station within 10 degrees, . . ." Dr. Pickard [27] has written that he demonstrated on September 13, 1907 that it was possible to obtain bearings at 38 miles with a maximum error not greater than 2°.

Notwithstanding the development of directional receivers, limited transmitting and receiving ranges reduced their utility

as a navigational aid. Necessity, that good old mother of invention, took a hand during the World War.[10], [28] Radio frequency amplifiers were developed. These amplifiers were added to directional receivers which were thus made very sensitive. The loop range was no longer limited. The Germans employed directional radio devices to guide their Zeppelins over England.[28] The English installed a number of groups of three to four direction finding stations, which were operated to plot the locations of German submarines by taking bearings on their radio transmitters. Thus the areas in which submarine activity was noted were avoided.[28]

The English operated other direction finders to follow the radio activities of the German Fleet at Wilhelmshaven. Admiral of the Fleet, Sir H. B. Jackson, states [28] that the Battle of Jutland was due in no small part to directional radio. Bearing observations of the radio transmission from the German battleships were made during May 30, 1916 when Germans were preparing to put to sea. The radio bearings showed a change of $1\frac{1}{2}°$ indicating that the German Battle Fleet had left its base at Wilhelmshaven and had taken a position in the Jade River ready to put to sea. The British, therefore, immediately moved their Grand Fleet to select suitable positions for engaging the German Fleet.

VARIABLE ERRORS IN RADIO DIRECTION FINDERS.

It is not surprising that other sources of errors were found as the direction finding receivers were made more and more sensitive. The apparatus had become quite reliable for determining bearings during the daylight hours but as sunset approached, the radio bearings became very erratic. These erratic results continued throughout the night and until shortly after daybreak. Such errors [28] were noted by the observers operating direction finding stations in France in January 1915. A curve of the "night effects" was plotted. A theory, accounting for the variations, was soon advanced: The Heaviside-Kennelly Layer [29, 30] might cause reflections of the radio waves during the night hours, and such reflections could alter the apparent radio bearings.

Let us examine the theory further. Heaviside and Kennelly had predicted the existence of an ionized layer in

the upper regions of the earth's atmosphere. Their theory indicated that the sun's rays would cause a layer of ionization and that the reflecting ability of such ionized layer would vary between day and night. While the normal path of a radio wave follows a great circle along the surface of the earth, a component of the radiated wave will reach the reflecting layer. This component may be reflected and the reflected wave may return to the earth. While the reflected waves generally pass into space during the daylight hours, these reflected waves often return to the earth during night operations. When both the reflected wave and the direct wave are received, "night effects" are said to exist because it is usually night time when such reflections interfere with practical operations.

We have shown that a loop antenna is oriented to balance out both the electric and magnetic fields. If the reflected or sky wave is either abnormally polarized or of a different phase from the ground wave, or both, the induced electromotive forces would not be balanced out in the loop. It follows that reorientation of the loop will either produce a poor balance and an uncertain bearing, or a good balance and a false bearing.[31] Furthermore, while a bearing is being taken, the reflected wave may be changing due to changes in the reflecting layer. Further reorientation may be undertaken only to indicate a still different bearing. The correctness of the theory has been well supported by brilliant experiments by Breit,[32] Tuve,[(32)] Taylor,[33] Hulburt,[(33)] Heising,[34] Dahl,[35] Gebhard,[(35)] Hafstad[36] and others, who have not only detected the Heaviside Layer reflections, but have measured the height of the layer and its movements.

Eckersley, in a series of experimental and mathematical observations,[37] shows that the Heaviside Layer may account for the night effects of a loop or Bellini-Tosi directional aerial. While daylight bearings are fairly consistent (1/10° to 1/2° under favorable conditions to 1½° to 2° under less favorable conditions) the night bearings become unreliable at 20 miles and become very uncertain at 300 to 400 miles from the transmitter. The night fluctuations are greater in southern latitudes than in northern. Night effects were observed by Eckersley to exist on wave lengths of 300 to 5000 meters.

He took bearings on a radio transmitter situated at Damascus, by means of a direction finder located 400 miles away at Cairo. The true bearing was 50.5°; standard daytime deviation 0.5°; the night deviation 12° to 25°.

Other experimenters report observing much larger errors: Taylor [38] reports a variation of 90° within an hour; Pratt [39] mentions a shift of 100° in azimuth; Kinsley and Sobey [40] recorded a bearing changing 56½° in 13 minutes; Wright and Smith [41] noted bearing errors of − 80° and + 80° in 5 minutes; and Smith-Rose and Barfield [42] cite 120° to 220° errors. On the other hand, Pickard,[43] who took observations during 1918 at Otter Cliffs, Maine, and during August 1921 at Seabrook, New Hampshire, reports a maximum error no greater than 10°.

It should not be inferred from the foregoing reports that night effects make night radio direction finding impossible. A skilled operator could recognize the night effects; the operator could take a number of bearings; the clearly erroneous bearings could be discarded; and finally, an average bearing could be obtained. But such results depend a great deal upon the skill and judgment of the operator. Adcock [44] offered a solution. He proposed to use spaced vertical antennas, and to connect the antennas through shielded transmission lines to a goniometer. Since a vertical antenna is not responsive to vertically polarized waves travelling along its axis, sky wave response is greatly reduced. The Adcock Antenna System has been recognized as a means of the reducing night effect.

Wright and Smith [41] in their paper, "The Heart-shaped Polar Diagram and its Behavior under Night Variations," describe experiments in which night bearings obtained on a loop antenna operating at its minimum are compared to the loop operated at its maximum with a vertical antenna to provide a resultant cardioid pattern. Their report indicates that while erratic bearings were obtained on the loop null, accurate bearings were determined at the minimum of the heart-shaped pattern.

Another system [45, 46] for eliminating night effects has been used in Europe. In this system the transmitters which send spaced pulses are used. The receivers are provided with cathode ray tubes. The cathode ray is swept in synchronism

with the transmitted pulses so that the directly received pulses and the later received pulses, i.e., reflected pulses travelling the longer path, are separately indicated on the cathode ray tube. The directly received pulse is balanced out by orienting the directive antenna system. Thus the effect of the sky wave is eliminated by obtaining the true bearing from the ground wave. One of the objections to the impulse type of direction finding is the necessity of using a special type of transmitter. Another objection is that the impulse method is not well suited to automatic indications.

(To be continued in next issue)

Power Transmission During National Emergency.—Speaking at the Midwest Power Conference in Chicago recently M. W. SMITH, Manager of Engineering at the Westinghouse Electric & Manufacturing Company, presented various phases of power transmission during national emergency to engineers and educators from all parts of the country. As a result of the Administration's decision to have an adequate power reserve for war-time requirements, the utilities have been requested to provide a surplus of generating equipment, and strong ties set up between systems necessary to keep industrial and munition plants in operation in the event that local plants are badly damaged by air raids. Due to Government development of remote water power sites, said Mr. Smith, there has been a revival of interest in the last ten years in long distance transmission even though the economic situation has not changed in the least, and schemes which hitherto were discarded for economic reasons must now be reconsidered. Direct current transmission in its present stage of technical evolution is a long way from being an economically justifiable tool, and the present inverting equipment used to invert direct to alternating current is not yet an active competitor of alternating current in any situation where transmission can function as an economically justifiable venture. This dismisses direct current as a possible method of handling power during national emergency. Speaking of A.C. transmission, he stated that the increased cost of the conversion equipment and increased physical size of the transformer required for low frequency make this form of transmission also impractical. High voltage transmission is the best expedient, and it is Mr. Smith's opinion that reliable apparatus can now be developed with 330 kilovolts as the next practical step since at this voltage about 200,000 kilowatts of power can be transmitted straightaway over one line for a distance of 300 miles with a loss of about seven per cent. Taking advantage of the margin normally incorporated as insurance for almost perfect service, it is believed that the present power interchange capacity of lines could be increased from 50 per cent. to 200 per cent., depending upon the particular system. This increase would in many cases be adequate, especially with some reinforcement of local generation.

R. H. O.

SENSITOMETRY OF PHOTOGRAPHIC PAPERS.

BY

LOYD A. JONES AND C. A. MORRISON.*

ABSTRACT.

The fundamental principles and methods of the sensitometry of photographic papers established by Jones, Nutting, and Mees in 1914 are reviewed. The necessity for the use of intensity scale exposure rather than the older time scale methods is shown. An account of the evolution of the design of an optical wedge sensitometer to fulfill the required sensitometric specifications leads to the description of a new instrument used in this study of the sensitometric characteristics of photographic papers. Details of the complete sensitometric process are given. The resultant characteristic curves from the different types and grades of papers are described and interpreted. The typical characteristic curve of modern papers is discussed and a revised method of determining numerical values, which describe the curve for practical purposes, is given. The new interpretation of the shape of the shoulder region of the curve is significant with respect to the quality of tone reproduction. The new group of characteristic values—speed, maximum gradient, exposure scale, maximum density, and contrast—is defined and discussed. Numerical values obtained by the new sensitometric method are given in tabular form for most of the current types and grades of photographic papers.

INTRODUCTION.

The fundamental principles of the sensitometry of photographic papers were established in 1914 by the work of Jones, Nutting, and Mees.[1] They adapted to the case of photographic papers Renwick's expression for reflection density which had been determined from measurements of silver deposits on opal glass. In this way they obtained a form analogous to that of Hurter and Driffield's expression of density as a function of transmission, namely,

$$D_r = \log 1/R,$$

where R is the reflectance of the surface measured under specified conditions.

The work of these authors placed the sensitometry of papers on a basis of measurement comparable to that used for negative materials. By this method the characteristics of a

* Communication No. 737 from the Kodak Research Laboratories.

paper can be expressed in the form of a sensitometric curve in which the reflection density, D_r, is shown as a function of the logarithm of the exposure, log E, which is required to produce the density.

The basic principles then established are still valid. However, the altered characteristics of photographic developing-out papers, the use of new and improved forms of sensitometers, and the results of more recent investigations on the theory and practice of tone reproduction have changed considerably the conclusions previously published regarding the theoretical and practical significance of the reflectance density, D_r = log exposure relationship.

We shall review briefly the method of paper sensitometry as developed by Jones, Nutting, and Mees [1] which has served as the basis of later work.

Of prime importance in the development of the early methods was the measurement of the reflection density of the silver deposits for which, up to that time, no specific conditions had been established nor were there available suitable instruments for making such reflection density measurements. Since the original discussion of this subject still obtains, we shall quote the section dealing with the measurement of reflection density.*

"In considering the light reflected from any surface it is necessary to deal with two types of reflection; i.e., specular and diffuse. Almost all surfaces show to some extent both types of reflection, the relative amounts of the two depending upon the matness or glossiness of the surface considered. Now, for the best results in viewing a photographic print it is necessary that the conditions of lighting and the angle of view be such that none of the specularly reflected light enters the eye of the observer. If these conditions are not fulfilled a more or less distinct image of the source of illumination will be seen on the picture, thus producing glare and preventing a satisfactory viewing of the picture. Therefore, in order to obtain the best results a photographic print must be viewed entirely by light that is diffusely reflected from its surface.

"Since in practice pictures are viewed entirely by diffusely reflected light, then the sensitometric measurements, if they

* Reference 1, pp. 342–343.

are to be comparable with practical results, must deal only with diffusely reflected light. For this reason any instruments used for measuring the reflecting power of a deposit on paper must be so arranged that the specularly reflected light is thrown out, and only the diffuse taken into account.

"The great difficulty hitherto met with in measuring the light reflected from paper, has been the absence of any suitable instrument for measuring the light reflected from small areas.

"Bench photometers, similar to those used by Hurter and Driffield, could be adapted for the purpose, but are clumsy and difficult to use, while any instrument using polarized light

FIG. 1A.

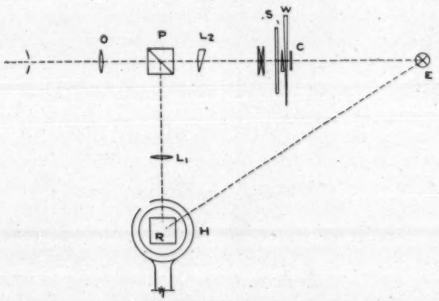
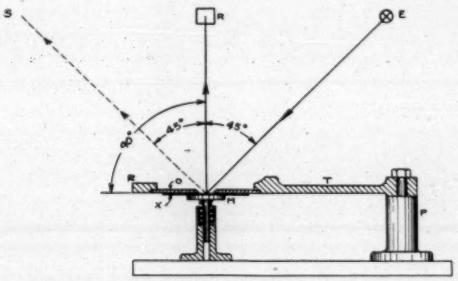


Diagram of optical system of modified Bechstein illuminometer used for measurement of reflection densities of photographic papers.

was subject to the suspicion that the light reflected from a paper surface might itself be partly polarized, which might seriously vitiate the results. This difficulty was overcome at the outset of our work by the use of the Bechstein illuminometer, which was modified to make it suitable for the measurement of the light reflected from small areas of paper prints. The arrangement of this illuminometer is shown in Fig. 1*A*, which is a projection on the horizontal plane of the essential parts of the instrument. The source of light, *E*, is a concentrated filament 100-watt tungsten lamp run off the lighting circuit. The light from this illuminates the screen *C* of thin solid opal glass. This screen is viewed through the

objective O, the photometer cube P, the rotating lens L_2, and the stationary adjustable sector S, the lens L_2 being rotated so that the opening of the sector S is integrated over the field, and the intensity of the beam transmitted by L_2 is, therefore, proportional to the aperture of the sector. This forms the outer field of the photometer cube P. The inner field consists of an image of the photographic print to be measured, which is placed in a suitable holder, H, on the table directly under the right angle prism R, an image of the small portion to be measured being formed on the cube by the lens L_1. The surface of which the reflecting power is being measured is

FIG. 1B.



Sensitometric strip holder for reflection densitometer.

illuminated by the same source, E, which is used as a comparison source; hence, variations in the intensity of this source are of no importance. The holder, of which a cross sectional view is shown in Fig. 1B, consists of a metal ring R carried at the end of an arm, T, projecting from the pillar P. In the ring is fitted a thin metal plate, O, in the center of which is an opening 4 mm. square, with edges bevelled and carefully blackened to prevent reflection. The sample X to be measured is placed under this opening and is pressed against the plate T by a flat-topped spring-actuated plunger M. In this way the paper is held perfectly flat and in a horizontal plane. The horizontal plane through EPR, Fig. 1A, occupies a position in space about 25 cm. above the plane of the paper in

the holder, and the distance from P to E is such that the light from E is incident on the sample in the holder at an angle of 45°. Since the right angle prism R through which the light enters the photometer cube is directly above the sample in the holder, and the paper is held in a horizontal plane, it is evident that the brightness of the image in the photometer cube is due to light that leaves the paper normal to the surface. Figure 1*B* shows the conditions diagrammatically. Light from source E is incident on the paper at 45°. The specular reflection, if any, goes in the direction OS, and is thus thrown out of consideration, while the light that illuminates the photometric field is reflected along OP normal to the surface of the print. Thus, it will be noted that the conditions of illumination and direction of observation used in measuring the reflecting power with this instrument are very similar to conditions existing when a picture is viewed by an observer."

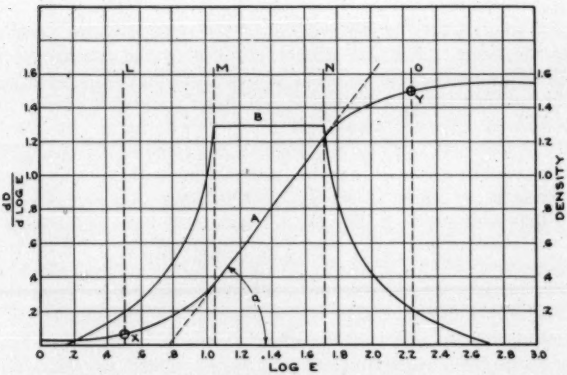
In the early work on this subject, the photosensitive papers were usually exposed in some form of time-scale sensitometer, although in some cases calibrated neutral gray density tablets were used, thus giving results on the basis of intensity-scale exposures. As a source of illumination, a calibrated tungsten incandescent lamp was used, which was operated at a color temperature of approximately 2800° K. This approximates fairly closely the quality of radiation used predominantly in practice for making prints. The prevailing exposure scale at that time was one in which the exposure increased from step to step by consecutive powers of the $\sqrt{2}$, $\Delta \log E = 0.15$. Later work has shown that for many photographic developing-out papers, especially those of the high contrast type, it is desirable to use scales in which the interval between steps is represented by consecutive powers of the cube root or even of the fourth root of 2 in order to establish the D-log E relationship with sufficient certainty.

After processing the exposed sensitometric strips, the reflection densities were read and the results shown graphically in the form of sensitometric curves, of which those shown in Fig. 2 are typical. Curve A represents the relationship between reflectance density, D_r, and log exposure, log E, while curve B is the first derivative of curve A. It was suggested that for some purposes the first derivative curve might exhibit

more clearly certain aspects of the characteristics of the material than curve *A*.

With regard to these curves, the authors made the following statement:* "Such curves give all necessary information about the paper, just as the corresponding curves do about plates or films, but just as in ordinary sensitometry, for convenience of record it is necessary to find some method of expressing the results obtained from the curves in a series of

FIG. 2.



Early form of generalized density-log *E* relationship of photographic papers.

constants, even if the constants give less complete information about the material than could be obtained by an inspection of the curve itself."

For the purpose of numerical record, the authors recommended that the following values be determined:

1. Maximum density ($D_{max.}$).
2. Gamma (γ).

   This was defined as the tangent of the angle alpha and is a measure of the slope of the straight-line portion of the *D*-log *E* relationship.

* Reference 1, p. 345.

3. Total scale (S).
   This was defined as the distance between the points X and Y on curve A, the points X and Y being located on the toe and shoulder, respectively, at the points where the slope of the D-log E relationship is equal to 0.2 (Fig. 2).
4. Latitude (L).
   This was defined as the length of the straight-line portion of the D-log E relationship measured in terms of exposure (or log exposure) units.
5. Rendering power (R).
   This was defined as the ratio of latitude to total scale, and to obtain a convenient number this ratio was multiplied by 10.
6. Standard exposure (E_s).
   This was defined as an exposure, expressed in candle-meter-seconds, required to give a just perceptible density on the material when exposed through a negative density of 2.0.

It is apparent that the authors in choosing these values followed quite closely the procedure that had been applied previously for expressing numerically in sensitometric terms the characteristics of negative materials. It is apparent now, after the years that have elapsed since this early work, that some of these numerical values or "constants" chosen have relatively little significance in expressing for practical purposes the characteristics of developing-out papers. In a later section of this paper dealing with the characteristics of modern developing-out papers this will be discussed more fully and proposals for the abandonment of some of the values mentioned above will be made, and modifications of some of the recommended definitions will be suggested.

Photographic papers are classified very largely, both by manufacturers and by consumers, with respect to that characteristic which is designated as "contrast." This characteristic, which is difficult to define, is probably, in the case of developing-out papers, of greater importance as an indication of their adaptability to various purposes than any other of their characteristics. A few years ago one of us published

a rather lengthy discussion of the subject of contrast [3] and an expression, based upon statistical and theoretical considerations, was proposed as a means of expressing numerically the contrast of a photographic paper. At that time a fairly complete bibliography of the subject was given. Since the publication of this paper several discussions of this subject have appeared in the photographic literature. Among these may be mentioned one by Bontenbal [4] in which the results of an extensive statistical study of the subject are reported. This contains also a bibliography up to 1937. Another by Renwick [5] discusses the contrast problem and its relation to the quality of tone reproduction and proposes a method for computing numerical values of contrast and for constructing an equalized scale of contrast steps. Because the present communication does not deal specifically with the subject of contrast, no attempt will be made to give a complete bibliography nor to analyze in detail the proposals of various authors for its evaluation.

The formula proposed by Jones [3] for computing numerical values of contrast has been in use in these Laboratories for the past several years and has been found to give results which appear to be in excellent agreement with the actual practical evaluation of that characteristic. This experience leads us to believe that the contrast formula in question is a satisfactory one, and the results obtained with it will therefore be examined in greater detail in the later sections of this paper.

AN INTENSITY-SCALE SENSITOMETER.

Sensitometry of photographic materials may be accomplished by the use of instruments of two fundamental types, viz., (1) the time-scale instrument in which the illumination, I, on the materials during the exposure is maintained at a constant value and the time of exposure, t, is varied, and (2) the intensity-scale instrument in which the illumination is modulated while the exposure time is held constant. The time-scale instrument has been developed to a higher degree of precision and reproducibility than the intensity-scale form and therefore has become established quite firmly in standard sensitometric practice. This situation has arisen primarily because no suitable intensity-scale sensitometer has been

designed which satisfactorily fulfills the requirements of precision sensitometry and is reproducible to specifications. Exposure timing systems may be controlled accurately through wide ranges of time by fundamentally simple mechanical contrivances while the modulation of light intensity through the desired range involves either cumbersome mechanisms or intricate and often unstable optical devices. Nevertheless, intensity-scale sensitometry is highly desirable as a basis of standardization and calibration of photographic materials because in practice they are nearly always exposed on an intensity-scale basis. Time-scale methods introduce the possibility of errors because of the failure of the reciprocity law which in many cases may be of considerable magnitude. These errors are entirely eliminated by intensity-scale methods, if the exposure times are comparable with those used in practice.

Exposure, E, is defined as the product of illumination, I, by time of exposure, t. An exact reciprocity law governing the production of silver in the developed photographic image requires that the amount of silver formed from an exposure, $E = I \cdot t$, be the same regardless of the magnitudes of the factors, I and t, as long as their product is constant. In most of the photographic materials as ordinarily used the law does not hold. This failure makes it essential that the conditions of exposure of the material under practical conditions be duplicated in the method of sensitometric test. Figure 3 illustrates the conditions involved in the failure of the reciprocity law. The four curves represent iso-density values of a photographic paper. The curves are determined by plotting the values of exposure, $\log I \cdot t$, against the factor $\log I$. No failure of the reciprocity law would give curves in the form of straight, horizontal lines; however, inspection of the curves as drawn shows that with low levels of illumination and long exposure times the exposure required to produce a given density is considerably greater than that required for the case when illumination is relatively high and time short. This trend reaches an optimal point at which I for this paper is about log 2.5 and then returns in the direction of the original values as illumination increases. Since these curves are not necessarily equidistantly spaced with respect to each other,

the shape of the sensitometric curve for various conditions of illumination and time may vary.

Any ordinate drawn across the curves represents a condition obtaining in time-scale sensitometry. Any line drawn across the curves at an angle of 45 degrees to the coördinate system determines a relation obtaining in intensity-scale sensitometry. Several of these 45-degree lines are labelled 1000 *s*, 100 *s*, etc., corresponding to various times of exposure. The ordinate at *a* at an intensity level of log 0.9 represents a typical time-scale sensitometric measurement with a maximum time of 80 seconds. This represents the older time-scale results. The 4-second intensity-scale line represents the new sensitometric method which is quite comparable with conditions of practical exposure. If the intercepts of the latter line and the iso-density curves are projected on to the ordinate *a*, marked differences on the $I \cdot t$ scale from the intercepts of line *a* and the iso-density curves will be seen. If we plot the density values against the $I \cdot t$ scale for each group of intercepts, we obtain the characteristic curves shown in the insert of Fig. 3. These curves show the large differences which may occur between the results of time-scale and of intensity-scale measurements.

The ideal sensitometer should fulfill the following specifications:

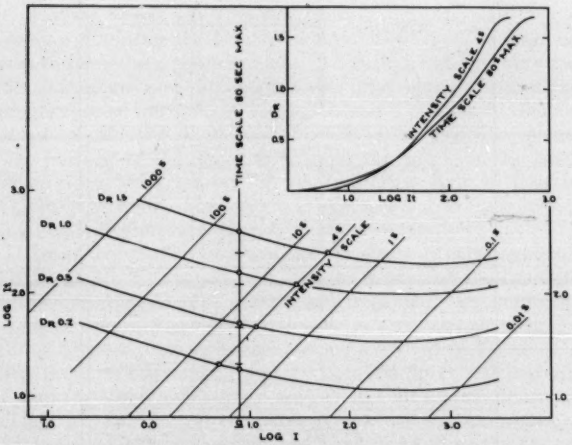
1. It should be of the intensity-scale type.
2. Illumination should be modulated by steps or continuously through a range of log $E = 3.0$.
3. Absolute level of intensity of maximum exposure should be variable from 1500 m.c. to 3 m.c.
4. Exposure time should be variable from 10 seconds to 0.01 second.
5. Provision should be made for the introduction of filters to (*a*) modify the total illumination and (*b*) modify the illumination on part of the exposure area.
6. Operating time should be reasonably rapid.
7. Accuracy and reproducibility of results should be within $\pm$ 2 per cent.
8. The instrument should be of convenient size and simple to operate.

An instrument meeting these specifications will serve to test sensitometrically all negative and positive photographic materials under exposure conditions comparable to those used in practice, with the exception of printing-out papers, recording papers, and x-ray materials.

The intensity-scale sensitometer described in the following pages satisfactorily meets these requirements.

Evolution of the Optical Wedge Sensitometer.—Many optical systems have been proposed which utilize cylindrical lenses in

FIG. 3.

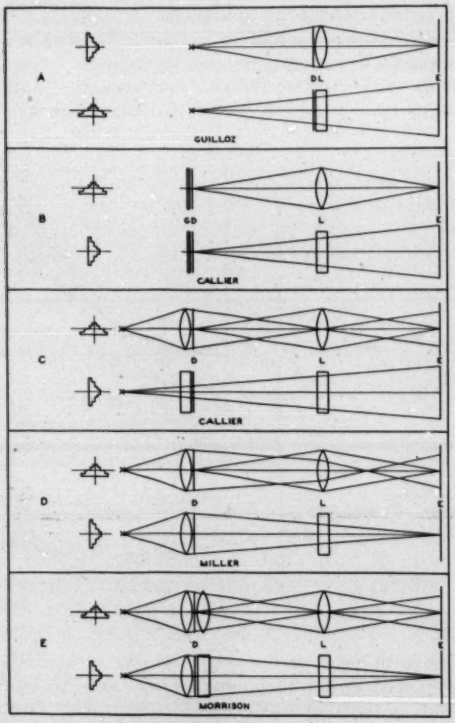


Reciprocity law failure diagram.

conjunction with a stepped or continuously wedged diaphragm to produce modulated illumination on an exposure plane. Figure 4 shows the schematic arrangement of several systems represented by Hansen's [6] convention of two orthogonal planes with the respective diagrams of the wedged diaphram. In all of these, the basic unit is the cylindrical lens *L*. Guilloz [7] in 1909 was the first to apply the principle. He used a continuously wedged diaphragm adjacent to a cylindrical lens which forms a continuously modulated intensity along a

slit (Fig. 4*A*). In this simple arrangement the use of the stepped wedge does not give a sharply defined image of the

FIG. 4.



Types of cylindrical lens systems.

steps on the image plane unless the source is actually a mathematical line.

Callier [5] in 1910 devised a spectrophotometric condenser (Fig. 4*B*) which produces sharply defined steps. The stepped

diaphragm is placed next to an evenly illuminated diffusing glass plate *G*. A cylindrical lens *L* images the diaphragm on the exposure plane *E* as a series of modulated steps of equal width. This combination of cylindrical lens and diaphragm becomes the basis of all later modifications. This system is not efficient in the utilization of the light owing to the diffusing glass. Callier [9] later suggested the use of a cylindrical condenser (Fig. 4*C*) in place of the diffusing glass as a means of increasing the efficiency. This condenser would image the source *S* as a strip of light on the lens *L*. This system is also not very efficient.

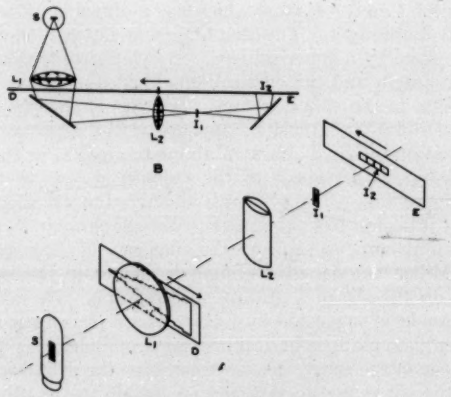
Hansen [6] used a system which has a diffusing plate at the stepped diaphragm. The diaphragm is imaged on the exposure plane by a spherical lens. A cylindrical lens between the diaphragm and the sperical lens images one plane of the diaphragm in the spherical lens. A series of sharply defined strips of different intensities appears at the exposure plane. The position of the diaphragm about the axis is in the same relationship with respect to the cylindrical lens as that in Guilloz's system. The system is effective but there is loss of light by diffusion from the plate at the diaphragm.

In an attempt to improve the efficiency of these systems, O. E. Miller [10] designed a system to modulate the light intensity on the slit of a grating spectrograph. He made the condenser lens, suggested by Callier as a replacement for the diffusing glass plate, spherical instead of cylindrical (Fig. 4*D*). The image of the source is formed between the cylindrical lens *L* and the slit in one section and on the slit in the other. A cylindrical field lens at the plane *E* in which the spectrograph slit is placed serves to prevent the loss of light when the system is used with the spectrograph. The diaphragm *D* is placed next to the spherical condenser. The resulting image on the plane *E* consists of a series of sharply defined steps of graded intensities. As with most of the systems of this type, the illuminated area is still too small and too low in intensity for practical application to sensitometry. Enlargement of the optical units of such a system to accommodate ordinary sensitometric strips requires parts of impractical size.

In 1933, J. W. McFarlane, of these Laboratories, proposed and built an experimental model of a system which utilizes

Miller's optical system as the basis of a sensitometer which permits the exposure of full-sized strips with an optical system of moderate dimensions. It is necessary to use a light source which consists of a uniformly radiating area, such as a ribbon filament lamp. Figure 5*A* shows in isometric projection the fundamental principles of the modification. The spherical condenser and the cylindrical lens are functionally the same as those in Miller's system. The horizontal aperture of the wedged diaphragm *D* is as long as the desired length of the

FIG. 5.



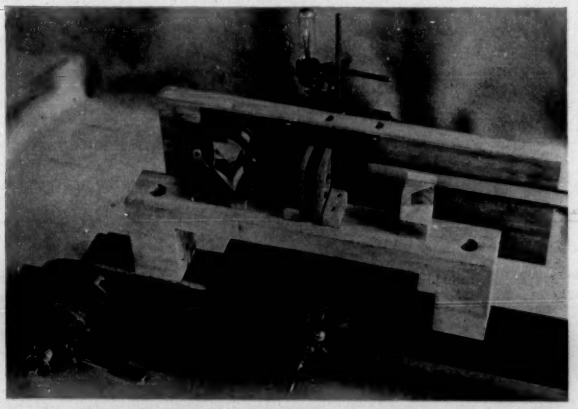
McFarlane's modification of Miller's optical system.

exposed part of the sensitometric strip. The diaphragm and the sensitometric strip are movable horizontally normal to the optical axis. In the horizontal plane the cylindrical lens images the diaphragm on the exposure plane with a magnification ratio of 1 : 1. If the diaphragm is moved lengthwise in one direction and the strip in the exposure plane is moved correspondingly in the opposite direction, any point of the diaphragm will be imaged at a point on the strip so that, by mechanically linking the motions of the two planes, it is possible to project a stepped image on the sensitometric strip,

although the dimensions of it and of the diaphragm exceed the aperture of the optical system.

The application of the system is shown diagrammatically in Fig. 5*B* and as experimentally built in Fig. 6. The parts were so mounted on a lathe bed that the diaphragm and the strip carrier were movable together along the bed while the optical system, including the light source, was fixed. By the use of two reflectors the motions of the diaphragm and the image were the same in direction and, by moving these at a

FIG. 6.



Experimental model of McFarlane's system.

uniform rate past the optical system, a series of stepped intensities was imaged on the sensitometric strip. This arrangement provides the basis for a sensitometer but the optical system is not of sufficient aperture or well enough corrected to meet the severe demands to be made upon it.

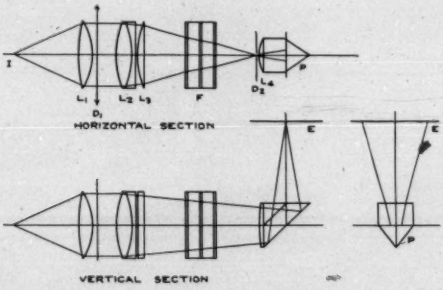
The Optical System.—A new system * was designed which

* Subsequent to the completion of this instrument an article by W. Kinder has appeared (*Zeit. für Instrumentenkunde.* 10, 393 1936) which reviews the development of cylindrical lens systems for photographic photometry. Some of the recent arrangements which, in principle, resemble the system described here, were used to test the relative transmission of various shutters.

would satisfy the requirements of high efficiency and large covering power. Figure 4*E* shows the system schematically. The fundamental use of the cylindrical lens to image the diaphragm on the exposure plane is retained. The diaphragm-illuminating condenser consists of a combination of Callier's suggested cylindrical condenser and Miller's spherical condenser.

The mechanical linkage of the system as devised by McFarlane does not allow sufficient room for the diaphragm system if the desired strip dimensions are to be kept without unduly increasing the dimensions of the optical units. One

FIG. 7.

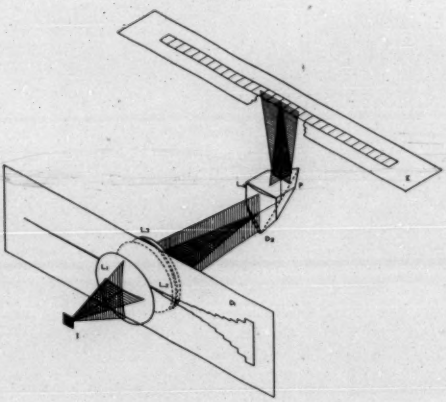


System of optics for new sensitometer.

of the schemes considered provides for the mounting of the optical system within a rotating drum which carries the diaphragm on one end of a diameter while the exposures are made at the opposite end. In order to simplify the mechanical parts in the final form of the instrument, the entire optical system and source of illumination are mounted on a moving base. The modulating diaphragm and the exposure aperture are fixed in the framework of the instrument. Diagrams of this arrangement are shown in Figs. 7 and 8. The former diagram follows, in general, the Hansen convention, and the latter shows the same in isometric projection to correspond in viewpoint with Fig. 9.

I is the uniformly radiating area of the source of illumination placed at the focal plane of the aspherical condenser lens L_1. The focal plane of a positive spherical achromatic doublet L_2 lies at the exposure plane E. This lens is corrected to complement the other units of the system. Lens L_3 is a cylindrical convex lens whose power, combined with that of L_2, images the light source in the plane D_2. Lens L_4 is a positive toric lens with very slight power in the vertical plane which images the wedged diaphragm D_1 on the exposure plane E with a magnification ratio of 1 : 1. Prism P is a

FIG. 8.

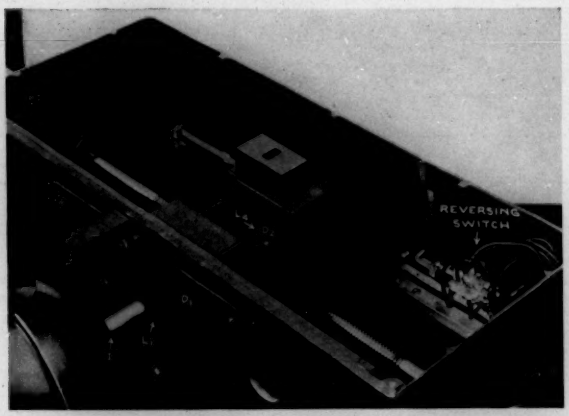


Isometric projection of optical system.

roof prism whose purpose is to translate the motion of the image of the moving diaphragm D_1 into a motion in the same direction as that of the diaphragm. The relationship of the position of the diaphragm D_1 with respect to the system is indicated in Fig. 4E. In the vertical plane the light source is imaged in the exposure plane E; the intensity in the exposure plane is therefore a direct function of the aperture of D_1. The width (across the smaller dimension of E, Fig. 8) of the images in the exposure plane is directly related to the height of the source. In the horizontal plane (Fig. 7), the light

source is imaged at D_2. The dimension of the light source in this plane governs the absolute intensity of the steps as imaged in plane E. Since the image of the source in this plane lies at D_2, the width of the rectangular diaphragm at D_2 serves as a control of the absolute intensity. It will be seen that, if D_1 is a stepped diaphragm, there will appear on the exposure plane a strip of illuminated areas of different intensities of uniform width with sharp dividing lines between the steps produced entirely by optical means. Figure 9 is

FIG. 9.



Interior view of sensitometer to correspond in position with Fig. 8.

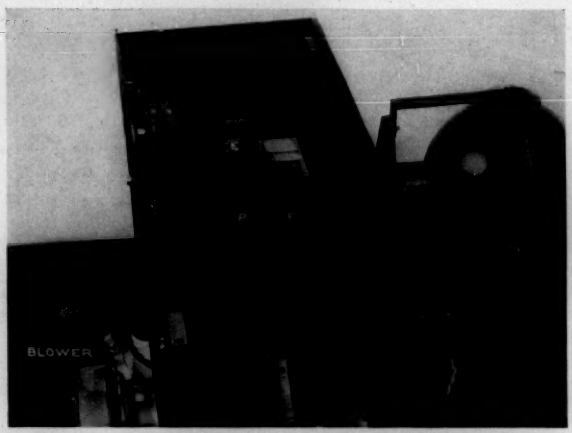
an upper rear view of the instrument from the same position as that represented by the optical system diagram shown in Fig. 8.

The entire optical system, including the light source, is mounted on a base which slides along ways (Figs. 10 and 11). Diaphragm D_1 and the exposing aperture for the entire strip of sensitive material are stationary in the housing of the instrument. As the optical system is moved with a uniform speed along the ways, the graduated step images are projected on the sensitometric strip for an interval of time equal

to that required for the aperture of the system at the exposure plane to pass a given point. Filter, *F* (not shown in Fig. 8), is of the Davis-Gibson type. A distilled-water dummy filter is used for unfiltered illumination in order to maintain the correct optical path. Gelatin filters may easily be inserted in this position with it.

The Light Source.—Astigmatic optical systems such as have been described are very often used to illuminate the slits of spectrographs and spectrophotometers. When used for these purposes there is no need for special forms of lamp filaments, since striation of the image, caused by irregular forms of sources, in the long dimension of the slit produces no detrimental effects in the image of the spectrograph. In the case of application to sensitometry, however, it is necessary to obtain uniform illumination over the wedged image at right angles to the direction of wedging. This can only be obtained in a system without diffusing plates, if the area of the source imaged on the exposure plane is a uniformly radiating surface or aperture.

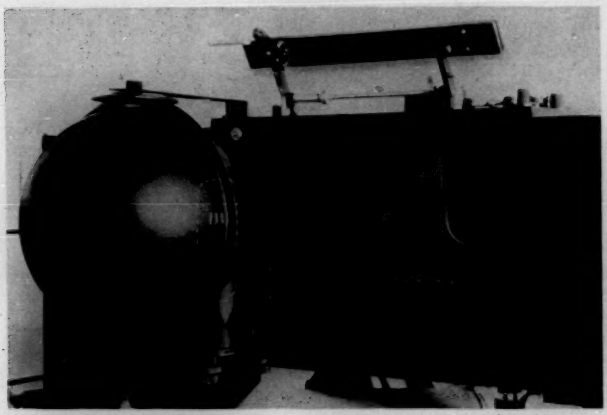
FIG. 10.



Sensitometer showing interior.

The source of light in this instrument is the aperture of an integrating sphere containing lamp bulbs. Ribbon filament lamps in an ordinary type of housing were tried but, owing to the slight warping of the filament plane and the resultant effects in the high-aperture optical system, they were not satisfactory. The integrating sphere was found to be the most stable source. For general use with papers, two 750-watt projection bulbs are installed. Since the input of such a unit is of the order of 1100 watts, a ventilating system is

FIG. 11.



Rear view showing lamphouse and stepped diaphragm.

necessary to maintain satisfactory operating conditions. The sphere consists of two spun aluminum hemispheres, eight inches in diameter. The position of one of the symmetrically placed bulbs is outlined in Fig. 11. The interior surface of the sphere is coated with aluminum oxide which may be produced chemically or deposited by the use of high-vacuum evaporation of aluminum. The coating is durable under the high-temperature conditions, is of high reflecting power, and is spectrally quite nonselective in the range required.

The Wedged Diaphragm.—The diaphragm D_1 may be constructed in various ways, as follows:

(1) With separate metal slit jaws for each step mounted adjustably on a template.

(2) With apertures cut in a single metal plate.

(3) With apertures ruled from silver deposited on glass and protected by cover glass.

(4) With each aperture on a separate plate by method (3).

(5) With apertures made by evaporating metal, such as aluminum, on glass over an accurately cut template, which when removed from contact with the glass after evaporation of the metal leaves a diaphragm resembling that in method (3).

Methods (4) and (5) are used in this instrument. Although methods (1) and (2) are free from reflections from the glass plates found in other methods, they were not used because of the difficulty of manufacture. No difficulty is experienced from reflections in methods (3), (4), and (5) if care in adjustment be taken.

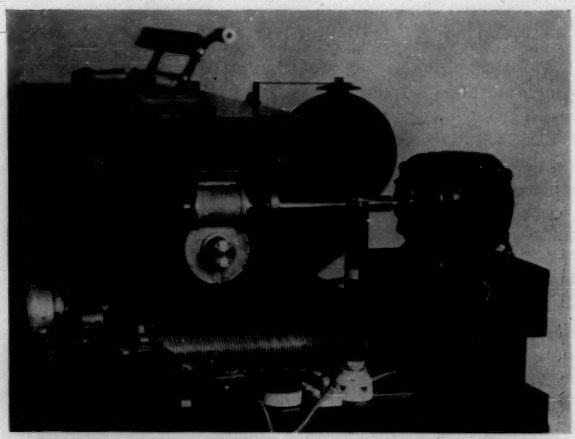
The diaphragms used in this instrument have thirty steps, each 8 mm. long in the major dimension of the diaphragm. The first step is 40 mm. wide and each successive step is reduced in width in the ratio of $\sqrt[3]{2} : 1$. The ratio between the first and thirtieth step is 1000 : 1 (log 3.0). The dimensions of the diaphragms may be made to meet the requirements of any number of steps and ratios, provided that the largest step does not exceed 40 mm. in width and the smallest is not less than about 0.03 mm. The latter dimension is limited by diffraction effects. For the sensitometry of photographic papers, it is desirable to use steps whose ratio of increment is no greaer than $\sqrt[3]{2}$ (log 0.10).

A stepped diaphragm, D_1, in the instrument is shown in Fig. 11. The evaporated-aluminum-on-glass diaphragm lies behind the supporting plate, which has a stepped aperture slightly larger than the actual diaphragm.

The Mechanical System.—The entire optical system and the illuminating system are mounted on a base which moves along two slides (Fig. 10). This unit is driven by a synchronous condenser type motor (Fig. 12) through a special hour-glass worm and worm wheel, which is mounted on the

end of the long screw passing under the moving unit and connected with the latter by a floating nut. The reduction between the motor and the screw is 12 : 1 and the pitch of the screw is 4 mm. With this drive, a strip 240 mm. long is exposed in about 30 seconds. A complete operation of inserting, exposing, and removing a strip takes about 45 seconds. The maximum exposure time for any given point on the strip is 4 seconds. By changing the diaphragm D_3 at the exposure plane, the exposure time may be proportionally reduced to

FIG. 12.



Side view showing motor and gear drive to worm.

about 0.1 second by the reduction of the aperture. This range may be further increased or decreased by the introduction of gear changes in the drive.

The motor is governed by an automatic switch actuated by the clamp lid over the exposure plane aperture. When this lid is lowered, the motor is started. When the exposure has been completed, the moving carriage releases the lid, which swings upward and opens the switch to stop the motor. The carriage meanwhile has tripped a mercury switch (Fig. 9)

which reverses the motor connections so that when the lid is again brought down, the motor will start in the reverse direction. The exposures are made equally well during either direction of carriage travel. The holder on the top of the instrument will receive strips 35 × 305 mm. on which the exposure area is 10 × 240 mm.

The interior of the sensitometer is kept light-tight by the attachment of two curtains (Figs. 10 and 11) to the carriage. These curtains unroll from spring-controlled rollers at each end of the instrument and cover the diaphragm except in the path of the optical system.

Exposure Control.—The instrument allows a wide range of exposing conditions. Time of exposure is controlled either by changing the length of the aperture of the diaphragm at the exposure plane, E (Fig. 7), or by altering the rate of carriage travel. The maximum diaphragm aperture is 40 mm., and with the normal gear ratio as described, the maximum time of exposure is 4 seconds. This time may be reduced to any value between 4 seconds and 0.15 second by changing the aperture proportionately. This may be done by changing aperture plates or by using mechanically moving aperture jaws. Separate plates are more accurately set and remain fixed in value. The absolute levels of illumination of the steps may be changed over a wide range without changing the lamp (1) by control of the horizontal dimension of the sphere aperture or (2) by control of the width of the diaphragm D_2 at the toric lens L_4. The latter is the better method. By changing diaphragm D_2 in horizontal width from 1 mm. to 16 mm., the intensity is changed proportionally or 16 times (log 1.2). Other levels of intensity may be obtained by using different lamps within the sphere. Quick changes are made by replacing the complete sphere with lamps as a unit.

Table I illustrates some of the combinations of diaphragms and the resultant exposing conditions attained with the instrument, using normal gear ratio and the 1100-watt lamp unit described previously.

Operating Characteristics.—The timing of the exposures is established by the use of a synchronous motor, and the accuracy of timing is equal to that of the frequency control

applied to the power line. The mechanical parts of the drive were thoroughly tested. The errors owing to irregularities in the worm and gear and the drive screw were found to be no more than a fraction of a per cent. when the exposure aperture was less than the pitch of the screw. An aperture larger than the pitch of the screw eliminates these errors.

The maintenance of intensity is limited only by the degree of control applied to the lamps in the sphere. The principal lamphouse contains two 750-watt tubular projection lamps operating on direct current at a potential difference consider-

TABLE I.

Diaphragm Combinations and Resultant Exposing Conditions.

Aperture		Exposure Time	For 40 mm. Aperture of Diaphragm D_1	
At E	At D_2		Log I m.c.	Log E m.c.s.
40 mm.	14 mm.	4 sec.	3.00	3.60
40	10	4	2.85	3.45
40	3	4	2.33	2.93
40	1	4	1.85	2.45
10	14	1	3.00	3.00
10	10	1	2.85	2.85
10	3	1	2.33	2.33
10	1	1	1.85	1.85
5	14	0.5	3.00	2.70
5	10	0.5	2.85	2.55
5	3	0.5	2.33	2.03
5	1	0.5	1.85	1.55

ably under their rating. This low operating level provides long life with a minimum change of radiation characteristics. Calibration has been done by photometry of the illumination at the exposure plane. If, in addition to this method, measurements were made of the brightness of the aperture of the lamphouse a constant could be established for the instrument which would allow the calibration of the spheres separately.

The final calibration of the instrument was checked by comparison of the sensitometric results obtained with the same materials tested on an extremely precise sensitometer which operated on the basis of the inverse square law. The

distances involved were as great as 11 meters and were subject to very precise measurement. The quality of the illumination on the exposure plane was made exactly comparable in the two instruments. Strips from the same sheet of photographic emulsion were exposed simultaneously in each instrument for exposure times of the same value. The exposed strips were then processed together. The sensitometric curves were plotted. The two curves did not deviate from each other more than the very small amount of error inherent in the method of plotting.

Spectral Absorption.—Paper emulsions are, in general, quite sensitive to radiation in the ultraviolet region, and in the case of materials which are also not very sensitive to radiation of wave-lengths greater than 400 mμ, relatively small changes in the amount of ultraviolet radiation transmitted by the instrument will have a marked effect upon the position of the sensitometric curve relative to the exposure axis. This instrument just described, like any which utilizes an optical medium such as glass plates or lenses in the path of the radiation used to expose the sensitive materials, is subject to errors because of the selective absorption by the optical system of radiation in the ultraviolet region. Most instruments previously used for sensitometry of photographic papers have shown a spectral cut-off at about 330 mμ. This instrument also shows similar characteristics; thus, the measurement of speed values is pratically comparable with those determined previously.

Photographic papers are usually exposed to the radiation of tungsten lamps, which are relatively deficient in the violet and ultraviolet regions. The resultant effect of the transmission of the tungsten radiation through the optical system is to cause a shift of the sensitometric curve along the exposure axis to a higher value, equivalent to a lowering of the speed of the material, without any significant change in the shape of the curve such as may occur in some cases if the selective absorption is within the visible region. As the sensitivity increases in the visible region, the error owing to absorption becomes progressively less. In practice, chloride emulsions are most subject to error because they are relatively less sensitive than bromide emulsions to visible radiation and are

most often used by more direct exposure to tungsten lamps. On the other hand, the bromide emulsions are less subject to error because they are more sensitive in the visible region and are more often exposed to tungsten radiation which has passed through the optical system of an enlarger, which is comparable in its selective absorption with the sensitometer. However, for all practical purposes, these effects may be neglected.

(To be continued in the next issue)

ARTIFICIAL RADIOACTIVE INDICATORS.

BY

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Radioactive substances have found frequent employ in the study of numerous problems entirely unrelated to radioactivity proper. The activity of the radioelement has served simply as a fortuitous means of measurement due to the ionizing properties of the emitted radiations. These properties permit the detection of extremely small quantities of radioelement and offer a way of distinguishing the radioactive form of an element from its more common, inactive isotope. When used in such a connection, the radioactive substance has been called a radioactive indicator (1). This sensitivity to detection, and the ease with which certain atoms in an isotopic or isomorphic mixture may be recognized constitute the basis of the many applications already found for the natural radioelements.

When these elements are used as indicators, the ratio of the active form to the inactive form may remain constant in all phases involved, in which case the element is simply a tracer which reveals the path of the inactive isotope. Frequently, however, the ratio is altered due to a distribution of activity between two sources of inactive isotope, and some type of exchange process is disclosed.

Thus by the simple expedient of "marking" or "labelling" or "tagging" certain atoms in a mixture, it has been possible to make solubility measurements, determine surfaces of crystalline precipitates, study the aging of fresh precipitates, follow adsorption and coprecipitation of ions, test a number of fundamental laws, examine alloy structures and diffusion processes, ascertain the distribution of certain elements in plants, etc., all with the aid of active elements occurring in nature (2).

Prior to 1934, an unfortunate restriction on the method had been the limited number of elements for which natural radioactive isotopes were available. With the realization that

radioactivity could be induced artificially, the whole field of applicability of radioelements as an aid in scientific investigations was expanded to such an extent that studies with almost all elements appeared feasible. Instead of being limited to lead, bismuth, thorium and thallium, radioactive isotopes of about eighty elements have been reported (3).

Not all of these will find use as indicators, certain limitations being imposed by the properties of the radioelement itself. One of these restrictions is the half-life which must be suitably long for convenient manipulation. Some seven active isotopes of zinc are known with half-lives varying between several minutes and several months. Were all equally readily available, the longer-lived of the isotopes obviously would be preferred since the half-life is much greater than the time required for most experiments, and the correction for the decay of the radioelement becomes small or even negligible. For shorter-lived elements, decay must be accounted for before activities may be compared.

Unfortunately all isotopes are not equally easy to obtain; some, such as the long-lived zinc isotope mentioned, requiring a cyclotron while for others (bromine, arsenic, etc.) a simple radium-beryllium source may suffice. Hence the available source is a second restriction. When rapidly-decaying elements must be used, it is desirable to have as high an initial activity as possible. This may be achieved by the use of a larger initial amount of irradiated substance and a more intense source of irradiation. It is superfluous to prolong the exposure time for periods greater than several times the half-life of the element sought, for any advantage accruing from longer exposures is diminished considerably due to the decay of the radioelement itself. Obviously it is seldom possible to prepare maximal quantities of very long-lived elements.

In Table I are listed the artificial radioelements which already have served as indicators, together with their half-lives and the nuclear transformations presumed to be responsible for their formation. Parentheses are preceded by the parent substance and followed by the resulting radioelement *; within are consecutively the impinging and emitted

* Subscripts, when given, are atomic numbers; superscripts are atomic weights.

TABLE I.

Artificial Radioactive Indicators.[a]

Radioelement.	Half Life.	Nuclear Transformation.[b]
Carbon	21 min.	${}_5B^{10}(d;n){}_6C^{11}$
Sodium	14.8 hrs.	$Na^{23}(d;p)Na^{24}$
Phosphorus	15 days	${}_{16}S^{32}(n;p){}_{15}P^{32}$; $P^{31}(d;p)P^{32}$
		${}_{16}S^{34}(d;\alpha){}_{15}P^{32}$
Sulfur	80 days	${}_{17}Cl^{35}(n;p){}_{16}S^{35}$; $S^{34}(d;p)S^{35}$
Chlorine	35 min.	$Cl^{37}(d;p)Cl^{38}$; $Cl^{37}(n;-)Cl^{38}$
Potassium	12.2 hrs.	$K^{41}(d;p)K^{42}$
Manganese	2.5 hrs.	$Mn^{55}(d;p)Mn^{56}$
Arsenic	27 hrs.	$As^{75}(n;-)^{76}$
Bromine	4.5 hrs.	$Br^{79}(n;-)Br^{80}$
	36 hrs.	$Br^{81}(n;-)Br^{82}$
Iodine	25 min.	$I^{127}(n;-)I^{128}$
Gold	2.5 days	$Au^{197}(n;-)^{198}$

[a] Data taken from a review by Guében (3).

[b] Notation of Fleischmann and Bothe, Ergebnisse exakt. Naturwiss., 14, 1 (1935).

projectiles. A hyphen signifies absence of emission; *n* stands for neutrons, *p* for protons, *d* for deuterons, and α for alpha particles. All of the above radioelements are electron emitters except carbon.

It is evident from the table that neutron and deuteron bombardment methods exclusively have been used as means of obtaining artificial radioactive indicators. As a rule slow neutrons simply attach themselves to the nuclei of elements, especially if heavy (note arsenic, bromine, iodine and gold). Nuclei of lighter elements (sulfur and chlorine) are apt to undergo a more complicated change, especially if faster neutrons are involved. The neutron source most frequently employed consists of a mixture of beryllium and radium or radon, the neutrons being emitted by beryllium under the combined influence of alpha and gamma radiations. Lithium and boron may be employed instead of beryllium if necessary. A richer source of neutrons results from the interaction between high speed deuterons and deuterium. The latter reaction is produced in the cyclotron (4) which steps up the kinetic energy of deuterium atom nuclei to an extent sufficient to produce a nuclear transformation. Radioactive substances

may be produced, however, by direct deuteron bombardment of elements other than deuterium; and the $(d; p)$ and $(d; \alpha)$ transformations listed in the table of indicators are all examples of this type of reaction effectuated with the aid of the cyclotron. Of course natural radioactive radiations such as alpha particles and gamma rays, also have served to induce radioactivity, though they do not constitute a practical means of preparing indicators.

Most artificial radioelements emit either electrons or positrons of relatively low energy. Furthermore the quantity obtained frequently is smaller even than in the case of natural radioactivity. Hence especially sensitive measuring devices must be employed. Various modifications of the Geiger-Müller counter (5) serve actually to discern individual particles as they are emitted, if an appropriate amplifying circuit is provided. Automatic recording devices likewise are available (6). Perhaps the simplest arrangement is that used by Paneth and Fay (7). Wherever a cyclotron is available, the activity of the artificial radioelement may be great enough to allow the use of an electroscope (8). A more detailed discussion of the equipment should be sought elsewhere (9) since the purpose of this paper is to summarize the applications so far found for the artificial radioactive elements as indicators.*

Most of the experiments with indicators involve a comparison between a control sample and an unknown. To obtain reliable comparisons, care must be exercised to duplicate conditions of the measurement. This requires that all samples be prepared in identical fashion, and that the position of the preparation be fixed with respect to the measuring instrument. The latter precaution is observed to insure reproducible scattering and absorption of radiation by air and metal parts interposed between the ionizing source and the ionization chamber. For electroscopes and flat counters, this restriction is imposed readily by means of proper mechanical adjustments. If tube counters are used, it is necessary to fasten a cylindrical tube (glass or celluloid) concentric with the

* The ease with which halogens may be radioactivated by neutrons is sometimes used as a means of demonstrating neutron emission. Iodine used for this purpose also has been called an "indicator." [Szilard and Chalmers, Nature, 134, 462 (1934).] This type of indication is not included in our discussion.

counter to provide a reproducible annular space for the sample, which may be either solid (10) or liquid (11). Others (12) have preferred simply to spread solid samples uniformly on a sheet of filter paper, covering this sheet with a thin layer of collodion, and measuring its activity directly or after wrapping the sheet around a tube counter. The same investigators (12) have measured the activity of liquids by collecting them in a spiral tube and inserting a tube counter coaxially inside the coil.

To prepare comparable samples is more difficult of realization since considerable error may be introduced by unequal absorption of emitted radiation by the samples themselves. This is true especially when solids are being examined. Contamination may cause errors due to differential absorption, and uncontrollable differences in size and shape of solid particles add to the uncertainty. Such discrepancies may be avoided by dissolving the solid samples and measuring the solution as such (11), or their residues after controlled evaporation. Before measurement, the inactive components in the solution should be regulated so that the composition of control and unknown are identical. It is also possible, by dilution with a solution of the same composition as the original, to prepare standards with activities of the same order of magnitude as unknowns, a condition which reduces incidental errors to a minimum. In biological and botanical works, sections of tissue have been measured directly without further treatment (13), and activity measurements on bone ashes have been made after simply dusting the ash on a glass slide.

Aside from their capacity to ionize gases, radioactive substances may be detected also by the effect of these radiations on a photographic plate. Radiograms have been extremely useful in studying the radiocolloid effect and mixed crystal formation (14) with the aid of the naturally occurring radioelements. The same property characterizes the artificial elements (15), in spite of the relative weakness of their radiations.

Separation of Radioelements.—Aside from the production and measurement of these elements there remains the problem of isolating and, if need be, concentrating the substance in question. Since radioelements differ from ordinary elements only in their activity, and not appreciably in their chemical

properties, customary microchemical and physical procedures may be exploited. These methods have been developed for the natural radioelements, and may be applied equally well to those produced artificially.

The task of recovering these minute amounts of radioactive substances is conditioned somewhat by the isotopic purity desired. Should experimental conditions demand that the radioelement in question not be diluted by any of its inactive isotopes, then the yield suffers in favor of enrichment of activity. Recovery is much more efficient when high concentration of the active form with respect to inactive isotope is of secondary importance; for then, appreciable quantities of inert isotope may be added until the yield is governed only by the customary analytical separations. In this manner the radioactive isotope is protected against loss by the preponderance of the inactive form, which carries (16) along the activity and assures the complete participation of the active form in any contemplated reaction. The role of the carrier is reminiscent of the function of "protective barium" in the storage of radium salt solution.

Practical methods used for obtaining artificial radioactive substances from an irradiated source may be classified as follows:

1. Electrochemical
   - Gas phase
   - Liquid phase
2. Chemical
3. Extraction
   - By solvents
   - By adsorbents.

Electrodeposition from the gas phase or from solution is a common procedure for the isolation of the natural radioelements (Ex: ThB, Po, etc.) and was applied early in the attempts at separating radioactive iodine (17) and arsenic (7, 18). When compounds such as alkyl halides or arsine are bombarded with slow neutrons, not only do the neutrons attach themselves to the nuclei of the heavy elements iodine and arsenic to form radioactive atoms of these same elements, but these artificial radioelements are ejected from the original

molecules as a result of gamma ray recoil (17). Actually these emitted atoms are charged and, in the case of arsenic, very likely are present as charged aggregates instead of as free atoms. Thus Fermi (17) and co-workers have attempted with little success to attract radioactive iodine atoms to a nickel electrode placed in ethyl or methyl iodide vapors subjected to neutron bombardment. Similarly, Fay and Paneth (7) could deposit on platinum and copper electrodes no more than 35 per cent. of the radioactive arsenic produced by neutrons in gaseous arsine. The deposit, however, was very pure active arsenic.

Fay and Paneth (7) investigated also the electrodeposition of halogens from neutron irradiated liquid organic halides, using copper and silver electrodes. With ethyl iodide it was possible to plate out on the anode all of the active iodine ejected from the molecule. They found the yield to be benefited by a trace of iodide ion which they produced by the interaction of a trace of free iodine and sulfur dioxide. This is undoubtedly due to an exchange which assures that the radioactive iodine will be in the ionic state. Complete recovery of radioactive phosphorus on a copper anode was reported by Govaerts (19) as a result of simultaneous electrodeposition and neutron bombardment of carbon disulfide.

Electrochemical methods should be of greatest service when one is called upon to separate ionic constituents from aqueous solutions. As a matter of fact, the first active copper prepared was isolated by currentless deposition (16) on a zinc plate after previous addition of inactive copper. Since then Haissinsky (20) has obtained active copper on a rotating lead plate with fair yields in the absence of additional nonradioactive isotope. Steigman (21) more recently has employed high-speed rotating metal disks and currents of about ten milliamperes for the plating process. Livingood and Seaborg (22) have separated radioactive antimony containing a trace of inactive element by currentless deposition on metallic tin.

Chemical separations are governed only by the usual chemical properties of the elements concerned, since the additional characteristic of radioactivity leaves these properties unchanged. In general the yield depends upon the

amount of inactive isotope added as carrier. One of the earliest chemical procedures is referred to as the Szilard and Chalmers (23) method. These workers irradiated with neutrons liquid ethyl iodide containing initially a trace of ordinary iodine. An aqueous solution of a reducing agent was added to reduce the iodine to hydrogen iodide which then was precipitated as silver iodide. By this means the active iodine was removed from the bulk of the ethyl iodide. An analogous procedure (24) permitted the recovery of active bromine from bromoform. Subsequent enrichment of the radioactive isotope is, of course, no longer possible. This practice of adding an inert isotope was adapted (17) also to the recovery of radio-elements from irradiated iodate, bromate, chlorate, permanganate, etc., and has been widely applied to insure efficient separation. In the case of the complex inorganic compounds referred to, the carrier was added in the ionic state. Thus a trace of chloride ion served to protect the radioactive chlorine against an inefficient removal from the bulk of the chlorate.

Roginsky and Gopstein (25) separated active bromine from neutron-irradiated ethyl bromide simply by shaking with an aqueous bromide solution. They claim more efficient extraction than by addition of free bromine as required by the practice of Szilard and Chalmers. This operation depends upon the exchange reaction between bromine and bromide ions which will be discussed below.

Majer (26) recovered active gold atoms by coagulation of colloidal gold formed in an irradiated alkaline gold chloride solution. Thus a trace of colloidal gold supplies condensation nuclei for the deposition of active gold atoms.

More recently Erbacher and Philipp have effected a separation of radioactive halogen atoms from irradiated alkyl halides by extracting the halogen in water (27), and by adsorption on active charcoal (28). Presumably any good adsorbent, such as silica gel or alumina, would serve. These methods show great promise as regards enrichment of active constituent. Roginsky and Gopstein (25) do recommend the use of aluminum oxide, especially for short-lived elements. The adsorption procedures have an additional advantage in that they are more rapid than ordinary chemical operations.

Thermal precipitation (29) also has been suggested as a possible method for a system such as radioactive arsenic in arsine.

Preparation of Radioactive Compounds.—One must confess that, frequently the most common methods—chemical and electrochemical—are characterized by relatively low yields. When ethyl iodide is irradiated by slow neutrons and the iodine recovered by the Szilard and Chalmers procedure, as much as 40 per cent. of the active iodine may remain with the alkyl halide (7). Similar deficiencies appear in attempts at electrochemical deposition from activated organic liquids. This low yield of free iodine is especially significant since gamma ray recoil energy (17, 30) is more than enough to break the carbon-halogen bond.

An explanation of this puzzling feature is found in a paper by Glückauf and Fay (31) who showed that part of the ejected active iodine atoms re-enter other molecules, exchanging for other groups present in these molecules. For example, 32 cc. (73 g.) of methyl iodide, in the presence of a small amount of protective methylene iodide and iodine, was irradiated by a slow neutron source (340 mc. Ra + Be). After one hour, 3 cc. (10 g.) of methylene iodide was added and the free iodine extracted with 46 cc. (50 g.) of an aqueous solution of potassium iodide and sulfur dioxide. Then the two organic halides were separated by fractional distillation, and the distribution of active iodine among the three liquids determined. Certain of these results are reviewed in the following table, the columns of which indicate respectively the organic compound which was activated, the percentage of total halogen recovered in the free state, the percentage left in the original compound, and the same for the new compound (in parentheses in column four) formed. As in the case of methylene iodide just described, these new compounds were identified by their inseparability from added amounts of the substance in question. Evidently 11 per cent. of the radioactive iodine has substituted for hydrogen atoms in methyl iodide to produce CH_2I_2. Considerable activity appears to remain in the original CH_3I, suggesting that the emitted active iodine atoms can replace halogen as well as hydrogen. That the effect is not due to an ordinary chemical reaction involving

substitution is supported by the absence of a temperature coefficient for the observed effect. The same percentage of the activity remains with the CH_2I_2 whether irradiation is carried out at 15° or at − 195°.

It appeared further that the active halogen atoms may replace not only other halogens and hydrogen, but may exchange as well with hydroxyl, amino, carboxyl and $-CH_2OH$ groups, in each case an active compound being formed. Undoubtedly other replacements are possible if the resulting compound is stable. The "replacement" method holds the possibility of yielding very concentrated sources of active halogen compounds. Thus by the simple expedient of irradiating methyl iodide in a large excess of benzene (itself

TABLE II.

Percentage of Total Activity Carried by Constituents after Separation (Glückauf and Fay).

Substances Irradiated.	Aqueous Extract (Free Halogen).	Original Substance Recovered.	New Product Found.
CH_3I at 15°.....	43%	46%	11% (CH_2I_2)
CH_3I at −195°...	44	45	11 (CH_2I_2)
CH_2Br_2.....	43	43	14 ($CHBr_3$)
$CHBr_3$.....	34	47	19 (CBr_4)
C_6H_5Cl.....	50	35	15 ($C_6H_4Cl_2$)
$CH_2BrCOOH$.....	78	(remained in aqueous extract)	22 (CH_2Br_2)

inert to neutron influences), practically pure C_6H_5I may be obtained after removal of benzene and methyl iodide. That these observations really constitute a method of obtaining radioactive organic halides was recognized by Glückauf and Fay (31) who suggest that the preparation of these active halides may be of special interest in medical research since many of them are specific anæsthetics.

This leads to a general consideration of ways and means of obtaining radioactive compounds. Direct synthesis from constituent elements is an evident if sometimes laborious procedure. Thus any radioactive compound may be prepared, given an appropriate and convenient active isotope. The synthesis of an active zinc salt, or a sulfate, for example, differs from the usual synthesis only in the use of radioactive

zinc or sulfur. The chemical properties of active and ordinary compounds are identical since the relative difference in masses of isotopes is too small to produce appreciable differences in reactivity.

Radioactive inorganic compounds may be obtained readily because of the great variety and speed of reactions which they undergo, and because of the large number of active elements accessible. On the other hand, great diversity in the preparation of radioactive organic compounds is hampered by the difficulty in obtaining active carbon. Consequently, although a recent abstract (32) announces the preparation of potassium oxalate containing active carbon, the radioactive organic compounds employed so far have been chiefly halogen containing substances. However, even in these cases, certain special methods are to be preferred to a synthesis which is apt to prove laborious. The paper of Glückauf and Fay (31) already has presented one such method. A second procedure for introducing radioactive halogen into organic halides is that of Brejneva, Roginsky and Schilinsky (12), who discovered that when ethyl bromide containing a small amount of aluminum bromide was subjected to neutron bombardment, no active bromine could be extracted with potassium bromide solution. This result was unexpected in view of the known rapidity with which the $AlBr_3-Br_2$ and $AlBr_3-HBr$ exchanges attain to equilibrium (25). Apparently the aluminum bromide, well-known as a halogenation catalyst, had catalyzed the re-entry of the radioactive bromine atom into the organic molecule. This suggested an exchange between the aluminum and alkyl bromides, and therefore a method of preparing radioactive organic halides according to the reaction

$$Al_2\overset{*}{Br}_6 + RBr = Al_2Br_6 + R\overset{*}{Br},$$

where the starred element is the radioactive constituent.* Undoubtedly active aluminum bromide was chosen as a starting material, in preference to direct bombardment of the

* $Al_2\overset{*}{Br}_6$ does not signify that all the bromine atoms are radioactive, since obviously there are insufficient $\overset{*}{Br}$ atoms to permit this. The designation implies simply that the molecule contains an active bromine atom. It may be written $Al_2Br_5\overset{*}{Br}$ just as $\overset{*}{Br}_2$ may be written also as $Br\cdot\overset{*}{Br}$.

aluminum and ethyl bromides because Roginsky and Gopstein also had noticed an effect resembling that of Glückauf and Fay. Furthermore, an exchange fixes the position of the radioactive halogen atom since there can be no question of bromination by free bromine as such.

The proposal just discussed is but one example of many possible exchange reactions which may be utilized. As a matter of fact any exchange of an element between two substances is a potential means of obtaining a radioactive compound. A number of such exchanges will be reported below. Controlled exchange of atoms between pure compounds is the ideal method of radioactivating a given substance, since, aside from its simplicity and speed, the desired substance is not contaminated by decomposition products resulting from the original exposure or by the replacement mechanism already considered (Table II). Actually the aluminum bromide used by Brejneva, Roginsky and Schilinsky was activated by an exchange with radioactive bromine or hydrogen bromide. To insure complete incorporation of the active element in the desired compound, it is necessary merely to take concentrations of exchanging substances such that the mass of the exchanging element in the initially inactive component exceeds by far the mass present in the active component. This follows from the fact that the distribution coefficient for isotopes is unity; therefore active bromine, for example, will ultimately distribute itself between compounds exchanging bromine atoms in a ratio of the amount of bromine in these components.

APPLICATIONS.

Even a cursory review of the natural indicator applications discloses the properties of radioelements which make them valuable as indicators. Paneth (33) showed by means of thorium C that bismuth hydride was a stable compound, although formed in extremely small amounts; and in these experiments the electroscope was the device for detecting about 10^{-15} g. of the hydride. Another early application of natural radioactive indicators was to an investigation (34) of exchanges between lead compounds, salts and non-electrolytes, in aqueous and non-aqueous media with thorium B as indi-

cator. Oxidation-reduction exchanges (34, 35) likewise have been investigated. The specific surface and aging studies (36) already mentioned constitute further examples of exchange or distribution of radioelements between two phases.

Clearly all that has been done with the natural radioelements may be extended by means of the artificial radioactive elements. Already a great many exchange reactions have been investigated; nor have botanical and biological workers failed to exploit these indicators to great advantage. These researches will be described in the following pages. First will be taken up those chemical applications which involve the use of active halogen, to be followed by a summary of experiments performed with radioactive phosphorus, sulfur, manganese and arsenic. A description of uses found for active gold will be followed by sections involving more extensive investigations of the mechanism and velocity of certain reactions. Botanical and biological uses of indicators will conclude the discussion.

Reactions Involving Halogens. (*a*) *Inorganic Systems.*—Most work by far has been done with radioactive iodine and bromine as indicators because of the relative ease with which they can be procured. Von Grosse and Agruss (37) were among the first to employ an artificial radioelement in an exchange reaction. They prepared 200 cc. of an aqueous solution containing 20 g. of sodium bromide, the bromine of which had been activated by neutron bombardment, and divided this into two 100 cc. portions. To one portion they added 24 g. of liquid bromine, the other serving as a control. Both solutions were evaporated to dryness and the activities of the residues compared. If the $\overset{*}{Br}^-$ distributed itself completely between Br^- and Br_2, then the removal of bromine would diminish the activity of the solution. This is readily seen on the basis of the following mechanism proposed by von Grosse and Agruss,

$$Na\overset{*}{Br} \rightleftarrows Na^+ + \overset{*}{Br}^-,$$
$$Br_2 + H_2O \rightleftarrows Br^- + H^+ + HBrO,$$

which takes into account the hydrolysis of bromine. For

* The asterisk indicates that the element is radioactive.

complete exchange, only 25 per cent. of the original activity of $\dot{Br}^-$ should be left after evaporation of the bromine. Actually 40 per cent. of the $\dot{Br}^-$ remained, which means that 80 per cent. of the maximum amount of bromide had undergone exchange. This discrepancy may be due to the fact that the rate of evaporation of bromine was greater than the rate of hydrolysis.

Roginsky and Gopstein (25) have contributed certain observations concerning the $Br_2 - Br^-$ exchange, based on the ease of extracting active bromide by washing neutron-exposed ethyl bromide with aqueous solutions of potassium, cupric, or hydrogen bromides. Exchange was rapid with all three bromides. These same workers attribute the exchange of activity to the formation of a complex Br_3^- ion, formed from potassium bromide and bromine in aqueous solution, and attempted to decide whether this complex possessed a rigid asymmetric structure $Br.Br_2$, or whether the peripheral bromine atoms were symmetrically disposed and oscillating more or less freely. A rigid structure would hinder complete exchange since the bromine atoms would not be equivalent one to another, whereas a symmetrical structure would presuppose an equal activity of all atoms hence assure an easy exchange. Thus bromine vapor was passed through a warm potassium bromide solution (either component being active) and the distribution of $\dot{Br}$ atoms measured. It appeared that the removal of activity was determined only by the relative amount of bromine in the bromine vapor and the bromide solution. More extended experiments were performed by alternate addition and removal of varying amounts of free bromine to the bromide solution at temperatures between 70 and 110° C. In each case the ratio of activities was equal to the ratio of the mass of bromine in the free state to that in the salt. The ease with which complete exchange could be attained was adduced as evidence for equivalence of the bromine atoms in Br_3^-, although the experiments do not exclude the mechanism of von Grosse and Agruss.

Topley and Weiss (38) have studied the bromine-bromide exchange in extremely dry carbon tetrachloride by adding to a

saturated (0.1 M) hydrogen bromide solution in carbon tetrachloride an equivalent quantity of radioactive bromine. They separated excess bromine by shaking with mercury, and converted this bromine as well as that remaining in the solvent into two silver bromide samples which were compared as regards their activity. Equipartition of activity required but two minutes at room temperature. A possible catalytic effect of the HgBr produced was excluded since the reaction $HBr + HgB\overset{*}{r}$ was shown to occur only to a small extent. On the other hand it seems unlikely that the rapid reaction is due to bromine atoms:

$$Br\overset{*}{Br} \rightleftarrows Br + \overset{*}{Br}$$

$$\overset{*}{Br} + HBr \rightleftarrows H\overset{*}{Br} + \overset{*}{Br}$$

since the equilibrium concentration of atoms is so small. Of course there are other possible mechanisms. A bimolecular reaction involving a collision complex may occur; or sufficient water may have remained to permit the formation of H_3O^+ and Br^- which may then exchange with $Br\overset{*}{Br}$ and with HBr.

In connection with their studies involving bromination catalysts, Roginsky and Gopstein (25) investigated the "kinetic" equivalence of bromine atoms in cupric bromide which decomposes when heated to the cuprous compound. Starting with radioactive cupric bromide ($Cu\overset{*}{Br}_2$), decomposition was effected at 250° and then the cupric salt reformed at 100° in the presence of inactive bromine vapor. The net result of such a series of steps is a 50 per cent. decrease in activity; and since the cycle was performed five times, there should be only about three per cent. of the original active bromine present in the final product. Actually about 50 per cent. of the original activity still remained, showing that after the first dissociation, succeeding treatments left the bromine atoms unaffected. Apparently the bromine atoms in cupric bromide are not equally reactive.

The researches of the Russian school have been extended to a general study of bromination catalysts, aluminum bromide having received most attention. Maintaining gaseous hydrogen bromide or bromine vapor in contact with solid

aluminum bromide at room temperature for ten minutes resulted in complete exchange, regardless of which component was radioactive at the start. By means of a flow system involving nitrogen as a carrier for bromine vapor or hydrogen bromide, Brejneva, Roginsky and Schilinsky (12) observed no

TABLE III.

Reactions of Inorganic Halogen Compounds.

Reactants.	Medium.	Result.	Author Reference.
$Br_2 + NaB\overset{*}{r}$	H_2O	Considerable exchange	(37)
$\overset{*}{Br}_2 + KBr$	H_2O (*a*)	Very rapid exchange (room temp.)	(25)
HBr	H_2O (*a*)	Very rapid exchange (room temp.)	(25)
$CuBr_2$	H_2O (*a*)	Very rapid exchange (room temp.)	(25)
$\overset{*}{Br}_2 + HBr$	Dry CCl_4	Complete exchange (2 min. at room temp.)	(38)
$Br_2 + H\overset{*}{B}r$	Gas phase	Complete exchange (15 min. at room temp.)	(12)
$I_2 + Na\overset{*}{I}$	H_2O (*a*)	Exchange (room temp.)	(39, 40)
$\overset{*}{I}_2 + IO_3^-$	1 N H_2SO_4 20 N H_2SO_4 (hot)	No exchange (room temp.) 10–15% exchange	(40) (40)
$\overset{*}{Br}_2(g) + Al_2Br_6(s)$	(*a*)	Complete exchange at room temp. (10 min. contact)	(12)
$H\overset{*}{B}r(g) + Al_2Br_6(s)$	(*a*)	Complete exchange at room temp. (10 min. contact)	(12)
$\overset{*}{Br}_2(g) + Al_2Br_6(l)$	(*a*)	Complete exchange (room temp.?)	(12)
$H\overset{*}{B}r(g) + Al_2Br_6(l)$	(*a*)		(12)

(*a*) The same result is obtained whichever component is active initially.

difference in rate of the bromine atom exchange with liquid or solid aluminum bromide. This suggests an unusual degree of mobility of the bromide molecules in the solid state, a mobility which approaches that in the liquid state.

The material discussed so far is summarized in Table III; together with certain other experiments involving inorganic iodine compounds in aqueous medium. It appears from the

reports of Juliusburger, Topley and Weiss (39) and of Hull, Shiflett and Lind (40) that the I_2-I^- exchanges occur as readily as does the Br_2-Br^- reaction. Hot concentrated sulfuric acid is required in mixtures of iodine and iodate (40).

Evidence for an extremely rapid exchange of radioactive chlorine between chlorine and chloride ion in aqueous solution is given by Long and Olson (41) who wished to compare the relative rates of the chlorine-chloride exchange and the chlorination of acetanilide. The formation of chloroacetanilide itself is immeasurably rapid and the chlorinated product precipitates out immediately as the added chlorine dissolves; yet a comparison between the chlorination and the exchange reactions of chlorine is possible if radioactive chloride ion is present initially. From the known amounts of Cl^- present and chlorine added, it is possible to predict the fraction of original active chlorine to be incorporated in the chloroacetanilide for extreme differences in the velocities of the reactions under consideration. In the event that chlorination proceeded with much greater rapidity than the exchange, no radioactive chlorine would be present in the chloroacetanilide. Should the exchange reaction prove to be much faster than the irreversible chlorination then the distribution of activity between the solid and solution would be governed by the relative number of moles of chlorine added (to an excess of acetanilide) and moles of initial chloride ion. The latter situation was shown to prevail by adding 0.00617 moles of chlorine to 500 cc. of an aqueous acid solution containing 0.03 moles of acetanilide and 0.075 moles of radioactive sodium chloride, and determining the fraction of the original activity which was removed by the chloroacetanilide. Of the initial activity 7.8 per cent. was so precipitated; the expected value was 7.0 per cent. Obviously the equilibrium between free chlorine and chloride ions is established instantaneously, and certainly before chlorination of acetanilide can begin.

Fowler and Dodson (55) have studied oxidation-reduction reactions of the halogens, though published details have not yet come to our attention.

(*b*) *Systems Involving an Organic Component.*—A large number of exchange reactions between organic and inorganic halogen-bearing compounds have been reported. Those ex-

periments which involve iodine and sodium iodide as the inorganic component will be treated first, and will be followed by a discussion of the reactions involving aluminum halides.

The behavior of methyl iodide and iodoform in various media containing free iodine or sodium iodide is reviewed in the two succeeding tables (IV and V). As one would expect,

TABLE IV.

Reactions of CH_3I.

Reactants.	Temp.	Medium.	Result.	Author Reference.
CH_3I+NaI^*	Room	Ethyl alcohol	>50% exchange per 1 min.	(39)
CH_3I+NaI^*	Room	Alcohol $\pm SO_2$	Exchange	(42)
CH_3I+NaI^*	Room	Acetone; amyl alcohol	Exchange	(42)
CH_3I^*+NaI	Room	Acetone; alcohol	Exchange	(42)
$CH_3I^*+I_2$	Room	Alcohol; CCl_4; CS_2; ether	No exchange	(42)
$CH_3I^*+I_2$	100°	Alcohol	Exchange in 15 min.	(42)
$CH_3I^*+I_2$	100°	No solvent	No exchange	(42)

Table V.

Reactions of CHI_3.

Reactants.	Temp.	Medium.	Result.	Author Reference.
CHI_3+NaI^*	Room	Acetone	<10% exchange in one min.	(39)
CHI_3+NaI^*	Room	Alcohol	No exchange	(40)
CHI_3+NaI^*	100°	Alcohol	Exchange	(42)
$CHI_3+I_2^*$	Room	Ether	No exchange	(40)

it is immaterial, when exchange takes place, which component of the system is active originally. Exchange of iodine between sodium iodide and methyl iodide in alcohol and acetone was found by McKay (42) to occur readily at room temperature. Free iodine is not a factor since the reaction is unaffected by sulfur dioxide. Solvents appear to weaken the

methyl-iodine binding. In iodoform, the iodine atoms seem to be more firmly bound since no reaction occurs with sodium iodide at ordinary temperatures.

Reaction with free iodine is more difficult to obtain than with the iodide. No exchange took place with pure methyl iodide even at 100° C.; and to produce an interchange at this temperature it was necessary to add alcohol, although even the presence of this and other solvents were ineffective at room temperature. Apparently molecular iodine dissociates

TABLE VI.
Reactions of C_2H_5I.

Reactants.	Temp.	Medium.	Result.	Author Reference.
$C_2H_5I+I_2$.....	90°	No solvent	No exchange after 15 min.	(40)
C_2H_5I+NaI....	Room	Alcohol	<10% exchange in 1 min.	(39)
C_2H_5I+NaI....	19°	Alcohol	Partial exchange in 5 min.	(43)
C_2H_5I+NaI....	24	Alcohol	Partial exchange in 5 min.	(43)
C_2H_5I+NaI....	29	Alcohol	Partial exchange in 1 min.	(43)
C_2H_5I+NaI....	29	Alcohol	Partial exchange in 5 min.	(43)
C_2H_5I+NaI....	50–55	?	Complete exchange in 15 min.	(42)
C_2H_5I+NaI....	80	Alcohol	Complete exchange in 5 min.	(43)
C_2H_5I+NaI....	100	Alcohol	Complete exchange in 1 min.	(43)

in organic solvents with greater difficulty than does sodium iodide. This may be due to a greater tendency of the free halogen to undergo solvation. These observations illustrate the fact that radioactive isotopes are useful agents for comparing the strength of interatomic linkages and the effect of solvents on this binding strength.

The behavior of ethyl iodide is described in Table VI. Its reactivity is less than that of the methyl compound. No exchange with free iodine is found, again illustrating the inertness of iodine towards an alkyl iodide.

We see that the C_2H_5I-NaI system has been studied over a range of temperatures. Unfortunately these measure-

ments are too qualitative to permit the calculation of an activation energy for the $RI-I^-$ exchange.

The interchange of iodine between sodium iodide and iodine in a number of other organic compounds is reported below (Table VII). This group contains both aromatic and aliphatic compounds. Here, as in other tables, the results are recorded as quantitatively as is permitted by the original sources.

Apparently iodine attached to a benzene ring is more firmly held than in aliphatic compounds. Iodo-aliphatic

TABLE VII.

Miscellaneous Reactions Between NaI and Organic Compounds*

Reactants.	Temp.	Medium.	Result.	Author Reference.
CH_2ICH_2COOH	Room	Water	No exchange	(42)
CH_2ICH_2COOH	100°	Water	≃complete exchange in 1–2 min.	(42)
CH_2ICOOH	Room	Water	Exchange	(42)
m- and *p*-IC_6H_4COOH	Room	Acetone	No exchange	(42)
$(CH_3)_2CHI$	Room	Alcohol	<10% exchange	(39)
$CH_3CH_2CH_2I$	Room	Alcohol	<10% exchange	(39)
$CH_2=CHCH_2I$	Room	Alcohol	<10% exchange	(39)
CH_2I_2	Room	Alcohol	<10% exchange	(39)
CH_2I_2	100°	Alcohol	Exchange	(42)
$(CH_3)_2CHI$	100	?	≃complete in 15 min.	(42)
$CH_3CH_2CH_2I$	100	?	≃complete in 15 min.	(42)
$CH_3CH_2CH_2CH_2I$	100	?	≃complete in 15 min.	(42)
$(CH_3)_2CHCH_2CH_2I$	100	?	≃complete in 15 min.	(42)
C_6H_5I	100	?	No exchange	(42)
p-$IC_6H_4NO_2$	100	?	No exchange	(42)
p-$IC_6H_4NH_2$	100	?	No exchange	(42)

acids contain rather loosely bound iodine. Methylene diiodide reactivity recalls the behavior of iodoform. The propyl iodides exchange very little, though a comparison with ethyl iodide is impossible since no high temperature experiments are recorded for the propyl compounds.

The preliminary report of Roginsky and Gopstein (25) intimated without elaboration of details that bromine atoms attached to carbon in compounds of the type $R-Br$ exchanged with great difficulty with polar molecules such as Br_2, HBr, $CuBr_2$ and KBr, even when ethyl alcohol was used as a

mutual solvent, or when the inorganic component was in aqueous solution and the whole system shaken vigorously. The bromination catalysts as Al_2Br_6 and $HgBr_2$, however, reacted with RBr with greater facility, complete exchange being observed at "high temperatures." This observation suggests that in these compounds the bromine atoms are undistinguishable as regards reactivity, a behavior opposite to that of the cupric bromide.

Systems of the type organic halide-aluminum halide have been the subject of a rather detailed study (Table VIII) by

TABLE VIII.

Reactions with $AlBr_3$ (No Solvent).

Organic Compound.	Temp. ° C.	Time (mins.).	Result.
C_2H_5Br	−30	0.5	Incomplete exchange
C_2H_5Br	+17	≃1	Complete
Isoamyl bromide	R.T.	20	Complete
$CHBr_3$	R.T.	20	Complete
$C_2H_4Br_2$	R.T.	20	Complete
$C_3H_6Br_2$	R.T.	20	Complete
$C_6H_5CH_2Br$	R.T.	20	Complete
C_6H_5Br	R.T.	20	7% exchange
p-$C_6H_4Br_2$	R.T.	20	10%
α-$C_{10}H_7Br$	R.T.	20	26%
$CHCl_3$	R.T.	20	Partial exchange
CCl_4	R.T.	20	
CH_3I	R.T.	20	No exchange
C_2H_5I	R.T.	20	No exchange
C_6H_6	R.T.	20	No exchange
$C_6H_5CH_3$	R.T.	20	No exchange

Brejneva, Roginsky and Schilinsky (12) who gave most of their attention to the $Al_2Br_6-C_2H_5Br$ exchange. They employ the term specific activity which is the ratio of the activity (in arbitrary units) of a component to the weight of active element (bromine in this case) which it contains. Thus we may write the specific activity for aluminum bromide as $\frac{a_{Al_2Br_6}}{m_{Al_2Br_6}}$ where a is the activity and m is the bromine content of a given weight of the bromide. For exchange equilibrium the specific activity is identical for both compounds and the ratio of activities of components equals the ratio of their bromine contents although, if the concentration of one member

of the system is sufficiently large, it will contain practically all of the active bromine.

The data compiled in the accompanying table (VIII) were obtained in the main by adding a known amount of active aluminum bromide to an excess of the organic compound and then measuring the activity of components after a given time. Separation was effected, usually after twenty minutes at room temperature, by addition of water to hydrolyze the aluminum bromide and converting the resulting hydrogen bromide to the silver salt for measurement. As a check on the distribution of activity, the residual organic compound could be distilled into a spiral tube wound to admit a tube counter along its axis.

All of the aliphatic bromides examined exchanged completely within twenty minutes. A lower limit of about one minute was set in the case of ethyl bromide. A more decisive test of equilibrium distribution of $\overset{*}{\mathrm{Br}}$ atoms was made with $\frac{m_{Al_2Br_6}}{m_{C_2H_5Br}} = 0.59$ instead of with a large excess of the organic halide. After twenty minutes the ratio of activities $\frac{a_{Al_2Br_6}}{a_{C_2H_5Br}}$ was 0.63 indicating equilibrium had been reached between $Al_2\overset{*}{Br}_6$ and ethyl bromide. Lowering the temperature of the $Al_2\overset{*}{Br}_6-C_2H_5Br$ solution to $-30°$ C. resulted in a considerably decreased exchange. A later, more accurate investigation (58), placed the activation energy of this reaction at 11,000 calories per mole.

The aromatic halides were distinguished by their lack of reactivity as compared with the aliphatic compounds. Benzyl bromide, with a brominated aliphatic side chain, behaved as a typical aliphatic bromide, while aromatic hydrocarbons proved to be inert. Again we have direct evidence of the greater firmness with which halogens are bound to the benzene ring as contrasted with aliphatic halogen. For the polybromides it was demonstrated that all the bromine atoms were equally reactive. For bromoform, ethylene bromide and dibromopropane, the values of $\frac{a_{Al_2Br_6}}{a_{RBr}}$ after twenty minutes

were respectively 0.53, 0.64, and 0.79 in a given set of experiments. Assuming all bromine atoms in the organic molecules as equally exchangeable, the values of $\frac{m_{AlBr_3}}{m_{RBr}}$, which constitute the limiting values of the ratios of activities, were computed as 0.73, 0.83, and 0.80 for this series. On the basis that only one bromine atom can participate, the expected activity ratios would have been 2.20, 1.66, and 1.60. Obviously the latter supposition is ruled out.

Partial exchange occurred in twenty minutes with chloroform and carbon tetrachloride showing that aluminum bromide reacts with these halides to form organic bromides, though much more slowly than do the organic bromides. Ethyl and methyl iodides were totally inactive. A rapid exchange of active iodine was found to occur between ethyl iodide and aluminum iodide whereas aluminum chloride was reported as exchanging with neither RBr nor RI. Details were not given, nor was the nature of the R specified.

These experiments have a direct bearing on the mechanism of the catalytic action of halogenation catalysts. The exchange between RX and Al_2X_6 involves either a dissociation of components or a collision between compounds involving the formation of a complex of the type $R[AlX_4]$. A dissociation mechanism seems to be contradicted by the failure (25) to find a rapid exchange between RBr and Br^-, whereas the assumption of complex formation is in agreement with the known tendency of aluminum halides to form complex compounds. The limiting distribution of active halogen between the organic and inorganic halides indicates equivalence of all bromine atoms, which is construed as evidence for a symmetrical arrangement of bromine atoms in such a complex instead of a rigid structure of the type $RX.AlX_3$.

Before leaving the qualitative halogen exchanges, mention should be made of an attempt by Kolthoff and Yutzy (44)to measure the specific surface of a silver chloride sample by shaking the precipitate in a solution containing active chloride ions and measuring the remaining activity as a function of time. The surface corresponding to the break in the adsorp-

tion vs. time curve was calculated in the usual manner by means of the expression (2a)

$$\text{sp. surf.} = \frac{\overset{*}{\text{Cl}}_{\text{adsorbed}}}{\overset{*}{\text{Cl}}_{\text{left}}} \times \frac{(\text{Cl}^-)_{\text{soln.}}}{\text{wt. AgCl}}.$$

(*To be continued in the next issue*)

SOMMERFELD'S FINE STRUCTURE CONSTANT AND BORN'S RECIPROCITY.

BY

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SUMMARY.

The problem of the electronic charge distribution together with that of the magnitude of Sommerfeld's fine structure constant $\alpha = 2\pi e^2/hc = 1/137$ is reduced to a *linear homogeneous integral equation* for the density amplitude ψ. The kernel depends on the parameter α, and every value of α determines an eigenfunction. One eigen value α and one eigenfunction is selected by an additional condition which is, the energy balance. The results are based on a hyperbolic sine relation between the momentum measurements of an inside and an outside observer, and on a similar relation between the space measurements of the two observers. Whereas the relations in momentum space are derived from the familiar Einstein energy-momentum equation, the space geometry of the particle is obtained by an application of the principle of reciprocity of M. Born.[1]

§1. EXTERNAL VERSUS PROPER OBSERVER OF THE PARTICLE. NEW SPACE GEOMETRY OF THE PARTICLE.

When a particle is accelerated from $p = 0$ to a momentum p (as observed by an outside observer), we may ask, what would be the *proper* increase of this momentum for an observer who is placed on the accelerated particle itself? The answer can be derived from the Einstein relation between energy and momentum (for an outside observer):

$$(\epsilon/c)^2 = (m_0c)^2 + p^2$$

or, when using reduced values

$$E = \epsilon/m_0c^2, \qquad P = p/m_0c, \tag{1}$$

from the equation

$$E^2 = 1 + P^2 \qquad \text{hence} \qquad E\cdot dE = P\cdot dP, \tag{2}$$

defining a *hyperboloid* in the $EP_xP_yP_z$ space. An increment dP is the projection of an increment dP' on the hyperboloid

$$dP' = (dP^2 + dE^2)^{\frac{1}{2}}.$$

The proper value of this increment is obtained, however, by

[1] M. Born, *Proc. Roy. Soc. A*, 165, p. 291, 1938.

dividing dP' by the proper unit of length which is, by the distance $(P^2 + E^2)^{\frac{1}{2}}$ of the line element from the center:

$$dP^0 = \left(\frac{dP^2 + dE^2}{P^2 + E^2}\right)^{\frac{1}{2}}$$

for which we can write, by virtue of (2)

$$dP^0 = \frac{dP}{(1 + P^2)^{\frac{1}{2}}}. \tag{3}$$

The momentum increase from 0 to P for an outside observer thus corresponds to a proper increase from 0 to

$$P^0 = \int_0^P \frac{dP}{(1 + P^2)^{\frac{1}{2}}} = \ln\left[P + (1 + P^2)^{\frac{1}{2}}\right] = \text{Sinh}^{-1} P.$$

Vice versa we have

$$P = \text{Sinh } P^0. \tag{3'}$$

For small values of $P = p/m_0c$ the difference between P^0 and P is negligible. But if p is as large as h/D where D is the electric diameter of the particle, the ratio P to P^0 becomes of the order of 100, as was shown in a Letter to the Editor of the Physical Review.[2]

Next we ask for the volume element dW in the ordinary P-space as compared to that in the proper momentum space, dW^0. The volume element in the curved space of the hyperboloid (2) is

$$dW' = dP_x dP_y dP_z\left[1 + \left(\frac{\partial E}{\partial P_x}\right)^2 + \left(\frac{\partial E}{\partial P_y}\right)^2 + \left(\frac{\partial E}{\partial P_z}\right)^2\right]^{\frac{1}{2}}$$
$$= \left(\frac{1 + 2P^2}{1 + P^2}\right)^{\frac{1}{2}} dW.$$

The proper value of this volume element is obtained by dividing dW' by the proper unit of length (not by its cube, because the Lorentz contraction applies only to the longitudinal direction):

$$dW^0 = \frac{dW'}{(P^2 + E^2)^{\frac{1}{2}}} = \frac{dW}{(1 + P^2)^{\frac{1}{2}}}. \tag{4}$$

These formulae are consequences of the *Einstein* equation (2).

[2] A. Landé, *Phys. Rev.*, Sept. 1, 1938.

We now introduce a new set of formulae relating the space measurements of an outside observer to those of an internal observer. If r is the distance from the center, we introduce a dimensionless reduced distance R and *postulate a new geometry* for the inside observer of the particle. His reduced line element shall be (compare with (3))

$$dR^0 = \frac{dR}{(1 + R^2)^{\frac{1}{2}}};$$

hence

$$R = \operatorname{Sinh} R^0, \tag{5}$$

and his volume element (compare with (4))

$$dV^0 = \frac{dV}{(1 + R^2)^{\frac{1}{2}}}.$$

These relations are derived from an equation *reciprocal* (in the sense of *Born's principle of reciprocity*) to Einstein's equ. (2):

$$(ct)^2 = (\gamma e^2/m_0c^2)^2 + r^2,$$

$$\frac{dr}{dt} = c\sqrt{1 + \gamma e^2/m_0c^2r)^2} > c \tag{6}$$

with a numerical factor γ. Introducing

$$R = rm_0c^2/e^2\gamma, \qquad T = tm_0c^2/e^2\gamma, \tag{6'}$$

our new fundamental equation of the particle reads

$$T^2 = 1 + R^2. \qquad \frac{dR}{dT} = \sqrt{1 + (1/R)^2}. \tag{7}$$

If t is interpreted as the time for a *signal* travelling along r then (6) means that the time $\gamma e^2/m_0c^3$ is saved from infinity to the center of the particle. This agrees with an earlier result of *Dirac's*,[3] who derived from *classical* considerations that the time saved by a signal from infinity to the center of the particle is $2e^2/3m_0c^3$. Thus $\gamma = 2/3$ might be correct, although Dirac's result concerns only the *major part* of the signal, and $\gamma = 1$ might still be true.

[3] P. A. M. Dirac, *Proc. Roy. Soc. A*, 167, p. 148, 1938.

§2. TWOFOLD COORDINATION OF PROBABILITY AMPLITUDES. THE INTEGRAL EQUATION.

In terms of the dimensionless quantities R and P (1) (6′) and of Sommerfeld's fine structure constant $\alpha = 2\pi e^2/hc$ we can write

$$\frac{2i\pi}{h} p\cdot r = i\alpha\gamma PR = i\alpha' PR \qquad \text{with} \qquad \alpha' = \alpha\gamma. \quad (8)$$

The density amplitude in space and the abundance amplitude in momentum space (for an outside observer) are then related by the equation

$$\psi(R) = \left(\frac{\alpha'}{2\pi}\right)^3 \int\int\int \chi(P) \exp\left[i\alpha'(P\cdot R)\right]\cdot dW \quad (9)$$

and its inversion

$$\chi(P) = \left(\frac{\alpha'}{2\pi}\right)^3 \int\int\int \psi(R) \exp\left[-i\alpha'(P\cdot R)\right]\cdot dV. \quad (9')$$

We are now going to apply quantum theory not only to the external but also to the internal observer. The latter shall be supposed to live in a world with a "natural" quantum of action h_0 relating his proper momentum and space coordinates. Since both worlds are related by the transformation formulae of §1, h_0 will be calculable from h. Or, putting

$$h = 2\pi e^2/c\alpha \qquad \text{and} \qquad h_0 = 2\pi e^2/c\alpha_0, \quad (10)$$

α_0 will be calculable from α and $\alpha_0' = \alpha_0\gamma$ from $\alpha' = \alpha\gamma$. In the present state of the theory we know α to be near 1/137. This will lead in §3 to a "natural" value of α_0 near *unity*. A future theory might start from assuming α_0 to be unity and then try to calculate the numerical value of the fine structure constant α.

Quantum theory in the proper system shall be governed by the equation, using α_0' instead of α',

$$\chi^0(P^0) = \left(\frac{\alpha_0'}{2\pi}\right)^3 \int\int\int \psi^0(R^{0\prime}) \times \exp\left[-i\alpha_0'(P^0\cdot R^{0\prime})\right]\cdot dV^{0\prime} \quad (11)$$

and its inversion analogous to (9) (9′). (The letters $R^{0\prime}$ and $V^{0\prime}$ are written instead of R^0 and V^0 in order to have R^0

available later.) It is plain that two quantum theories, one with h and one with h_0 in the two spaces cannot co-exist in general. But the point is that if we *postulate* them to co-exist then we come to a special case, to a ψ-function representing a *particle*. (9) connects ψ with χ, (11) connects ψ^0 with χ^0. In addition we have the following relations between χ, ψ and χ^0, ψ^0:

$$\psi^2 dV = (\psi^0)^2 dV^0, \qquad \chi^2 dW = (\chi^0)^2 dW^0, \tag{12}$$

completing the cycle $\psi\chi\chi^0\psi^0\psi$. Thus, beginning with ψ in (9) we substitute on its right under the integral

$$\chi(P)dW = \chi^0(P^0)\sqrt{dWdW^0}$$

(see (4)). Then we replace $\chi^0(P^0)$ by the integral (11) over $\psi^0(R^0)$ and substitute

$$\psi^0(R^{0\prime})dV^{0\prime} = \psi(R')\sqrt{dV'dV^{0\prime}}.$$

In this way we arrive at the integral equation

$$\psi(R) = \left(\frac{\alpha'\alpha_0'}{4\pi^2}\right)^{\frac{1}{2}} \iiiint \Big[\iiiint \exp(i\alpha' PR) \times \exp(-i\alpha_0' P^0 R^{0\prime})\sqrt{dWdW^0}\Big]\psi(R')\sqrt{dV'dV^{0\prime}}.$$

In the case of spherical symmetry we obtain easily

$$\psi(R) = \left(\frac{\alpha'\alpha_0'}{4\pi^2}\right)^{\frac{1}{2}} \int\Big[\int \frac{\sin(\alpha' PR)}{(\alpha' PR)} \frac{\sin(\alpha_0' P^0 R^{0\prime})}{(\alpha_0' P^0 R^{0\prime})} \times \frac{4\pi P^2 dP}{(1+P^2)^{\frac{1}{2}}}\Big]\psi(R')\frac{4\pi(R')^2 dR'}{(1+R'^2)^{\frac{1}{2}}}, \tag{13}$$

where P^0 and P, $R^{0\prime}$ and R' are related by (3′) and (5). (13) is a homogeneous integral equation for $\psi(R)$ with the kernel

$$K(R, R', \alpha', \alpha_0') = \left(\frac{\alpha'\alpha_0'}{4\pi^2}\right)^{\frac{1}{2}} \int_0^\infty \frac{\sin(\alpha' PR)}{(\alpha' PR)} \times \frac{\sin(\alpha_0' \operatorname{Sinh} P \operatorname{Sinh} R')}{(\alpha_0' \operatorname{Sinh} P \operatorname{Sinh} R')} \frac{4\pi P^2 dP}{(1+P^2)^{\frac{1}{2}}}. \tag{14}$$

The kernel is unsymmetric in R and R' and contains the two

parameters $\alpha' = \alpha\gamma$ and $\alpha_0' = \alpha_0\gamma$. If one of them is given then every value of the other leads to a solving eigenfunction ψ, normalized to unity. We now introduce the additional condition[4]

$$\int\int \frac{1}{R_{12}} \psi(R_1)^2 \psi(R_2)^2 dV_1 dV_2 = \gamma, \tag{15}$$

that is, because of $R = rm_0c^2/e^2\gamma$, the condition that the electrostatic energy of the charge cloud shall be m_0c^2. This additional condition then selects one eigenvalue α', if α_0' is given, and vice versa. The theory is based on two ideas: (A) the classical equation $T^2 = 1 + R^2$ reciprocal to $E^2 = 1 + P^2$; (B) the coordination of the quantum functions ψ, χ of (9) and ψ^0, χ^0 of (11).

§3. APPROXIMATE SOLUTION OF THE INTEGRAL EQUATION.

Before trying to solve the integral equation (13) we must get acquainted with the kernel (14). Its values for various arguments cannot be obtained without much numerical work. But we may try at least a very rough approximation, not so much in order to obtain numerical results than to study the general type of problem involved. Our approximation shall consist in replacing the functions $(\sin x/x)$ under the integral (14) by *zero* for values $x > 2\pi$, and by a *constant* C for $x < 2\pi$. The integral in (14) then reduces to

$$J = C^2 \int_0^{P^{0*}} 4\pi \,(\text{Sinh } P^0)^2 \,(\text{Cosh } P^0)^{\frac{1}{2}} \, dP^0.$$

Instead from 0 to ∞ the integral runs from 0 to an upper limit P^{0*} which is the *smaller* of the two values P^{0*} defined by

$$\alpha_0' P^{0*} R^{0'} = 2\pi \text{ resp. } \alpha' \text{ Sinh } P^{0*} \text{ Sinh } R^0 = 2\pi.$$

That is, P^{0*} is the *smaller* of the two values

$$P^{0*} = 2\pi/\alpha' R^{0'} \text{ resp. } P^{0*} = \text{Sinh}^{-1}\,(2\pi/\alpha' \text{ Sinh } R^0). \tag{16}$$

The kernel (14) is thus

$$K(R^0, R^{0'}, \alpha_0'\alpha') = \left(\frac{\alpha'\alpha_0'}{4\pi^2}\right)^{\frac{1}{2}} 4\pi \,(\text{Sinh } R^{0'})^2 \,(\text{Cosh } R^{0'})^{\frac{1}{2}} \, J(P^{0*})$$

[4] For this additional condition as well as for many important critical remarks I am very much indebted to Prof. L. H. Thomas

where J is now to be considered as a function of its argument P^{0*}. So we have *two cases*:

$$\text{Sinh } (2\pi/\alpha_0' R^{0'}) > 2\pi/\alpha' \text{ Sinh } R^0. \qquad (17\text{ I})$$

Here K is an asymmetric function of R^0 and $R^{0'}$.

$$\text{Sinh } (2\pi/\alpha_0 R^{0'}) < 2\pi/\alpha' \text{ Sinh } R^0. \qquad (17\text{ II})$$

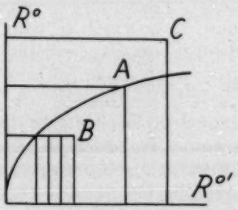
Here K depends on $R^{0'}$ alone and not on R^0.

The boundary between the two cases is given by the equation

$$\text{Sinh } (2\pi/\alpha_0' R^{0'}) = 2\pi/\alpha' \text{ Sinh } R^0, \qquad (18)$$

representing a boundary *line* in the $R^0 R^{0'}$ plane drawn in fig. 1. The point A on this curve marks the point where R^0 equals $R^{0'}$. When solving the integral equation (13) with

FIG. 1.



the simplified kernel we may first try to get a solution for a *finite* range of R^0, supposing that ψ outside of this range is *negligible*. The kernel is then to be defined in a corresponding finite range, that is, within a finite square of fig. 1. Three such cases are drawn in fig. 1 supposing that ψ is negligible beyond A, B, C respectively. At the same time one may approximate the integral equation by a system of linear homogeneous equations for the values of ψ at various points $R_1^0 R_2^0 R_3^0 \cdots$. The kernel is then the determinant of the set. Its elements are

$$K_{mn} = K(R_m^0 R_n^{0'}).$$

Now if α' is such as to produce the case I, then the determinant is an unsymmetric scheme of elements K_{mn}, and the

determinant will not vanish in general. In case II however, the determinant will have many equal columns. Thus the integral equation will have not only one but many independent solutions. The only case where there is *one* definite solution is found at the boundary between the two cases. If in fig. 1 we consider the three squares A, B, C resp. as being filled with the elements K_{mn} of the determinant K, then the square B contains many equal columns, entered as vertical lines. The column C does not contain equal columns at all. Only the square A represents the boundary case where equal columns just begin to appear, leading to *one* definite solution of the integral equation.

Thus, for a certain value of α_0' we have first to draw the boundary line (18) in the $R^0R^{0\prime}$ plane. Then we have to find the point A on it where $R^0 = R^{0\prime}$. This point is determined by the equation

$$\text{Sinh } (2\pi/\alpha_0' R^0) = 2\pi/\alpha' \text{ Sinh } R^0,$$

that is by the equation

$$\text{Sinh } (2\pi/\gamma\alpha_0 R^0) = (2\pi/\gamma\alpha R). \qquad (19)$$

(The factors 2π on both sides are due to our neglecting of $\sin x/x$ beyond $x = 2\pi$.) In order to satisfy the additional condition of the electrostatic self energy we have to deal with a ψ function that is negligible outside the usual electrostatic radius $r = 2e^2/3m_0c^2$, that is, we have to take R in (19) equal to $2/3\gamma$, and R^0 equal to $\text{Sinh}^{-1}(2/3\gamma)$. If $\gamma = 2/3$ (see end of §1) then $R = 1$ and $R^0 = 0.88$. Putting $1/\alpha = 137$ we then have on the right of (19) a number of order $2\pi \cdot 137$. However, $2\pi \cdot 137$ happens to be numerically close to Sinh (2π). Thus the argument of Sinh on the left of (19) must be of order 2π, and $\gamma\alpha_0 R^0$ of order unity. Since γR^0 is of order unity *the same must then be true of* α_0 *itself*. According to this very rough approximative consideration the appearance of 137 has its numerical origin in the fact that the ratio of 2π to Sinh (2π) is of order 1 to 137.

It gives me great pleasure that I can refer to a paper of M. Born's on the same subject to be published soon by the Royal Society of Edinburgh.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

EFFECTS OF HUMIDITY AND COMPOSITION ON ENAMELS.

Vitreous (porcelain) enamels are harder to break in dry weather than in damp weather, according to the results of a study recently completed by D. G. Moore and W. N. Harrison of the Bureau's Enameled Metals Section, and reported in detail in the *Journal of Research* for September (RP1237). Twenty-gage angle irons, 8 in. long, made by bending 8 × 2 inch strips of enameling-grade sheet iron, were enameled and tested by twisting until the enamel chipped at the apex. The angle of twist required to cause failure was taken as the index of resistance to chipping in torsion. For an enamel thickness of 0.015 inch, a decrease in relative humidity from 98 per cent. to 35 per cent. caused a 15 per cent. increase in the angle of twist required to produce chipping. The temperature was constant. Specimens given a thin coating of paraffin after firing, and before they had completely cooled, were tested at 98 per cent. relative humidity and withstood nearly a 30 per cent. greater angle of twist without failure than uncoated specimens tested under the same conditions.

Also, modulus of rupture was determined on fibers of enamel frit about 0.75 mm. thick. In a period of relatively high humidity, fibers of one frit showed a failure of 10 specimens out of 20 at the end of a 20-hour sustained-load test in which the stress was 9 kg./mm.^{2}. Later under the same conditions, except for lower humidity, this frit showed a failure of only three out of 20 specimens after the usual 20-hour sustained-load test. However, when a small drop of water was placed gently over the mid-point of each specimen, the remaining test fibers began breaking almost immediately and ten additional specimens had broken within 40 minutes, raising the percentage failure from 15 to 65. Calculations indicated that the weight of the drops of water could not

* Communicated by the Director.

have increased the maximum fiber stress by more than 0.03 kg./mm.^{2}.

Under controlled atmospheric conditions, the modulus of rupture of relatively fusible ground-coat enamel fibers increased from 4.7 to 7.2 kg./mm.^{2}, or more than 50 per cent., when the humidity was decreased from 90 to 56 per cent. in sustained-load tests. Under the same conditions, the strength of acid-resisting enamel-frit fibers increased from 8.4 to 9.7 kg./mm.^{2}, or 15 per cent.

When dried over $CaCl_2$ and tested under kerosene for modulus of rupture with increasing load, the ground-coat frit was 30 per cent. stronger than when stored in the open air and tested under water. The acid-resisting frit was 50 per cent. stronger.

Previous reports of other investigators have shown that such properties as the resistance of whiteware glazes to abrasion by falling sand, the transverse strength of glass bars loaded at placed scratches, and the tensile strength of fused-quartz filaments a few microns in diameter, are also affected by large changes in atmospheric humidity.

It is evident that, in future testing of the physical properties of materials such as vitreous enamels, glasses and ceramic glazes, atmospheric humidity should be taken into account in order to obtain consistent results.

REMOVAL OF SOIL CORROSION SPECIMENS.

Beginning early in September, specimens of ferrous and non-ferrous pipe and of certain protective materials which have been buried in the ground for various periods of from 2 to 17 years will be removed for inspection.

A few additional materials will also be buried for further test. K. H. Logan in charge of the Bureau's Soil Corrosion Section will supervise the work and will be glad to hear from those who may desire to witness the removal of specimens in their vicinity. Letters should be addressed to K. H. Logan, National Bureau of Standards, Washington, D. C.

The following materials were buried in 1922: Armco iron, wrought iron, Bessemer steel, open hearth steel, copper bearing steel, duriron, fiber, DeLavaud cast iron, pit cast iron, and lead.

The following materials were buried in 1924: Lead-coated pipe; three kinds of galvanized pipe and sheet; three kinds of bitumen-coated pipe; brass attached to lead, brass, or galvanized iron.

Two materials were buried in 1926: Copper pipe and brass pipe.

The above named materials will be removed in accordance with the following schedule, thus completing the tests at the sites named:

Test Site near	Coöperating Utility.	Official to See for Information.	Tentative Date for Removal of Specimens.
Alexandria, Va.	Water Dept.	Supt.	Sept. 5
Boston, Mass.	Gas Co.	Supt.	Sept. 14
Bunkie, La.	Standard Oil Co. of La.	Supt.	Nov. 13
Camden, N. J.	Water Dept.	Engineer	Sept. 8
Cincinnati, Ohio	Gas & Electric Co.	Supt. of Dist.	Sept. 22
Dallas, Texas	Gas Co.	Supt. of Dist.	Oct. 31
Davenport, Iowa	United Light & Power Eng. & Const. Co.	O. K. Smith, Chem. Eng.	Sept. 28
Jacksonville, Fla.	City Commission	Supt. Water Dept.	Nov. 17
Kansas City, Mo.	Gas Co.	C. H. Waring	Sept. 29
Los Angeles, Cal.	Southern Cal. Gas Co.	W. M. Henderson	Oct. 12 and 13
Meridian, Miss.	Water Dept.	Supt.	Nov. 7
Middleboro, Mass.	City	Town Manager	Sept. 15
Milwaukee, Wis.	Water Dept.	Supt.	Sept. 27
Oakland, Calif.	East Bay Municipal Utility Dist.	Chief Engineer	Oct. 6
Piqua, Ohio	Tidewater Pipe Co.	J. Z. Van Tine	Sept. 19
Salt Lake City, Utah	Mountain Fuel Supply Co.	Manager	Oct. 2
San Antonio, Texas	Public Service Co.	Supt. Gas Dept.	Oct. 23
Seattle, Wash.	Dept. Public Works	T. H. Carver	Oct. 4
Springfield, Ohio	Water Dept.	Supt.	Sept. 20

The following materials will be removed from the sites named in the next table. This will complete the tests at these sites. Armco Iron, wrought iron, Bessemer steel, "Monocast" iron, pit cast iron.

Test Site near	Coöperating Utility.	Official to See for Information.	Tentative Date for Removal of Specimens.
Atlanta, Ga.	Southern Cities Pub. Service	E. C. Kollock, Mgr.	Nov. 28
Charlotte, N. C.	Southern Public Utilities	Manager	Nov. 29
Cincinnati, Ohio	Union G. & E. Co.	Supt. of Gas Dist.	Sept. 2
Houston, Texas	Humble Oil Pipe Line Co.	R. A. Brannon	Oct. 24
Macon, Ga.	Gas Co.	Manager	Nov. 22
Pensacola, Fla.	Florida Public Utilities	Manager	Nov. 16
Phoenix, Ariz.	Water Dept.	Engineer	Oct. 20
Raleigh, N. C.	Gas Co.	Manager	Dec. 4
Salisbury, N. C.	Southern Public Utilities	Engineer	Oct. 20
Shreveport, La.	Southern Cities Distributing Co.	Burt Smith	Nov. 1
Tampa, Fla.	Gas Co.	Manager	Nov. 20
Vicksburg, Miss.	Gas Co.	Manager	Nov. 3

From the sites listed in the following table will be removed so-called corrosion resistant materials buried in 1932 and 1937. These include some of the commonly used pipe materials as well as a large variety of ferrous and non-ferrous alloys. About 15 kinds of non-bituminous pipe coatings will also be inspected. There are about 75 varieties of materials at these test sites. About 10 additional materials will be buried.

Test Site near	Coöperating Utility.	Official to See for Information.	Tentative Date for Removal of Specimens.
Atlanta, Ga.	Water Dept.	W. M. Rapp	Nov. 23
Baltimore, Md.	Water Dept.	Leon Small	Sept. 7
Beaumont, Texas	Gulf Pipe Line Co., Houston	Walter Rogers	Oct. 25
Button Willow, Cal.	San Joaquin Light & Power Co., Bakersfield	A. Y. Meudell	Oct. 11
Charleston, S. C.	Water Dept.	J. E. Gibson	Nov. 24
Kalamazoo, Mich.	Dept. of Public Utilities	E. E. Norman	Sept. 25
Los Angeles, Cal.	Shell Oil Co., Wilmington, Cal.	I. M. Hemphill	Oct. 16
Meridian, Miss.	Water Dept.	J. T. Pinkston	Nov. 6
Milwaukee, Wis.	Gas Co.	W. E. Kemmen	Sept. 26
New Orleans, La.	Public Service Co.	G. L. Rhodes	Nov. 9
Paso Robles, Cal.	Union Oil Co., San Luis Obispo	Lafe Todd	Oct. 9
Phoenix, Ariz.	Water Dept.	City Engineer	Oct. 19
Plymouth, Ohio	Ohio Fuel Gas Co.	H. S. Riddle	Sept. 18

METHOD OF DESIGNATING COLORS.

In 1931 the first chairman of the Inter-Society Color Council, Dr. E. N. Gathercoal, proposed on behalf of the U. S. Pharmacopoeial Revision Committee the problem of devising a system of color designations for drugs and chemicals. He said, "A means of designating colors in the United States Pharmacopœia, in the National Formulary, and in general pharmaceutical literature is desired; such designation to be sufficiently standardized as to be acceptable and usable by science, art, and industry, and sufficiently commonplace to be understood, at least in a general way, by the whole public." With the assistance of the American Pharmaceutical Association and following plans outlined in 1933 by the Inter-Society Color Council, D. B. Judd of the Bureau's Colorimetry Section and K. L. Kelly, research associate of the American Pharmaceutical Association, have worked out

a solution for this problem which substantially fulfills the requirements laid down by Dr. Gathercoal. The system is described in RP1239 in the September *Journal of Research*.

COMPARISON OF ACCELERATED AND NORMAL AGING OF RECORD PAPERS.

Retests at the Bureau of record papers that had been stored under normal conditions for 8 years give additional evidence of the good correlation between the effects of natural aging of such papers and accelerated aging by heating for 72 hours at 100° C.

The findings agree well with those obtained by a retest made 4 years ago. The retention of folding endurance of the papers under normal aging was of the same relative order as under accelerated aging. Furthermore, the same relation of chemical properties to the retention of folding endurance was found for both kinds of aging. The more stable papers were characterized by a good condition of cellulose, and by low or moderate acidity. Under both aging conditions, the cellulose of the better papers exhibited little change, but the inferior cellulose of the unstable papers became considerably more degraded, which indicated a breaking down of the fiber structure with consequent loss of strength. The Bureau recently tested some papers from old books that had been stored for 150 to 200 years. The papers had deteriorated greatly, apparently because of adverse storage conditions. They had lost practically all of their strength, and they showed the same kind of degradation of cellulose, to an exaggerated degree, as that found in the unstable papers stored at the Bureau.

These and many other of the Bureau's studies show that accelerated aging by heating is a useful guide in the grading of papers for stability. That such a guide is needed is illustrated by the wide spread in stability of the stored papers even in such a short period as 8 years; the best papers retained as much as 90 per cent. of their original folding endurance while some of the poorest retained as little as 15 per cent.

A complete account of this work is given in a paper (RP1241) by B. W. Scribner in the September number of the *Journal of Research*.

METHOD FOR SEALING PLATINUM TO PYREX GLASS.

CORRECTION.

The first item in the August issue of the JOURNAL contains an error carried over from the Technical News Bulletin for July.

In the sentence which begins in line 8 of the second paragraph of the article, the word "diameter" should appear instead of "length." That is, the sentence should read, "If the walls of the tube are thin as compared with its diameter. . . ." The second sentence of the second paragraph should also be qualified to indicate that the statement refers to glasses of low thermal expansivity, such as Pyrex.

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THE FRANKLIN INSTITUTE.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 680 readers made use of the facilities during the twenty-seven days of August.

RECENT ADDITIONS.

ARCHITECTURE AND BUILDING.

JENNINGS, BURGESS H., AND SAMUEL R. LEWIS. Air Conditioning Principles and Practice. First Edition. 1939.

ASTRONOMY.

LEE, OLIVER JUSTIN. Beyond Yonder. 1939.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

American Institute of Chemical Engineers. Transactions 1938. Volume 34. 1939.

Electrochemical Society. Transactions. Volume 75. 1939.

KALICHEVSKY, VLADIMIR A. Modern Methods of Refining Lubricating Oils. 1938.

MAY, PERCY, AND G. MALCOLM DYSON. May's Chemistry of Synthetic Drugs. Fourth Edition, Revised and Rewritten. 1939.

Mellor's Modern Inorganic Chemistry. Revised and Edited by G. D. Parkes in Collaboration with J. W. Mellor. 1939.

ELECTRICITY AND ELECTRICAL ENGINEERING.

CROWTHER, JAMES ARNOLD. Ions, Electrons, and Ionizing Radiations. Seventh Edition. 1939.

REED, HENRY R., AND GEORGE F. CORCORAN. Electrical Engineering Experiments. 1939.

ENGINEERING.

National Lumber Manufacturers Association. Wood Structural Design Data. Second Edition. Volume 1. 1939.

MATHEMATICS.

SIMONS, LAO GENEVRA. Fabre and Mathematics and Other Essays. 1939.

METALLURGY.

ROLLASON, E. C. Metallurgy for Engineers. 1939.

METEOROLOGY.

LINKE, F. Meterorologisches Taschenbuch. Vierte Ausgabe. 1939.

RAILROAD ENGINEERING.

VAN METRE, T. W. Trains, Tracks and Travel. Fifth Edition. 1939.

SUGAR.

Gilmore's Louisiana Sugar Manual. 28th annual Edition 1938–39.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

A NEON TUBE COUPLED AMPLIFIER CIRCUIT FOR RADIO COSMIC-RAY RECEIVERS.*

BY

S. A. KORFF.

The development of the technique of transmitting cosmic-ray intensities from sounding balloons by short wave radio has necessitated the design of a receiver and recorder unit for the ground station. An amplifier has been developed, which is connected to the output of a standard superregenerative short wave receiver, in order to convert the received signal into a pulse capable of operating a tape register. This circuit has been in use for over a year.

The action of the receiver has been previously described.[1] Briefly, the receiver is adjusted just above the point of regeneration, so that when no signal is being received, the regeneration hiss is heard. When the signal is received, regeneration is suppressed and the hiss ceases. Viewed on an

FIG. 1.

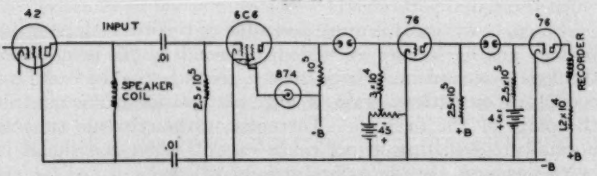


Diagram of neon tube coupled amplifier circuit.

oscillograph connected to the receiver output, a broad noise pattern is seen when the receiver is regenerating. Other noise is merely added to the background, and does not suppress regeneration for a time long enough to operate the recorder.

The diagram of the amplifier is shown in Fig. 1. The

* Reprinted from the *Review of Scientific Instruments*, 9, 256 (1938).

[1] S. A. Korff, L. F. Curtiss and A. V. Astin, *Phys. Rev.*, 53, 14–22 (1938).

first tube in the amplifier, a 6C6, functions as a detector. It is nonconducting while the receiver regenerates, and is conducting when regeneration is suppressed by a signal. When the 6C6 is nonconducting, the neon tube connected to its plate glows, since current flows from the (250 volt) B supply through the plate resistance to the neon tube and returns through the grid leak of the first 76. When the 6C6 becomes conducting, the voltage drop through it is small compared to the 67-volt drop across the neon tube. The neon tube is in effect short circuited, and ceases to glow. When the signal ceases, the 6C6 ceases to conduct, and the voltage of the plate of the 6C6 builds up to the potential required to start the discharge in the neon tube. It is thus evident that the neon tube is normally glowing in the absence of a signal, and not glowing when the signal is being received.

Since the other side of the neon tube is connected directly to the grid of the first 76, the starting and stopping of the discharge transmits a large voltage change to this tube. With the neon tube discharging, the grid of the first 76 will be positive, while if not glowing, the grid potential of the 76 will be determined by the grid bias battery, and will, in the case shown in Fig. 1, be strongly negative. A relay or recorder may be operated in the plate circuit of the 76. Such a relay would of course be normally closed, and would snap open when the signal is received.

Since, however, it is more desirable to record with positive pulses, another stage is added. The first 76 is coupled through a second neon tube to the second 76. In order to economize on battery drain, a large plate resistance is used in the plate of the first 76. Therefore, although this tube is normally conducting at all times except when the signal is being received, the plate current is kept low.

Two types of operation of the coupling tube are possible. The resistances and negative bias of the second 76 may be so chosen that the second neon tube is normally not glowing, and begins to glow when a signal is received, or the neon tube may be allowed to pass a feeble current in the absence of a signal, and will then pass more current when the signal comes through. The second type of operation is obviously equivalent to a direct coupled amplifier, with a 67-volt drop across the coupling unit.

The voltage change applied to the grid of the second 76 through the neon coupling tube is sufficient to change the 76 from entirely nonconducting to entirely conducting, and thus to permit any desired current in the plate circuit to be controlled. In this particular circuit, a maximum current of 15 milliamperes flows. A weak signal causes the full swing of 15 milliamperes to take place. Sensitivity may be further increased by adjusting the bias of the first 76, and the volume control of the receiver, so that a very faint signal will operate the recorder. In practice it is found that a signal so faint as not to be audible in the loudspeaker will work the recorder with certainty. On extremely faint signals, the neon tube does not entirely cease to glow, but merely passes less current. This action is quite sufficient to produce large changes in the plate current.

The recorder consists of a Western Electric type G-26 telephone relay, to the armature of which a pen is attached. The pen writes on paper (ticker) tape pulled by a geared down synchronous motor. The shortest signal to which this recorder will respond is about 0.1 second. The result of so long a "time constant" is a failure to respond to noise. Most short wave radio noise, such as produced by static, automobile ignition or electrical machinery, has a component on the wavelength to which the receiver is tuned. However, the pulses are generally of short duration. Hence they do not operate the recorder. The time constants of the amplifier are short, the longest being 0.0025 second. Hence the circuit can be used for high speed work. An oscillograph connected in place of the recorder showed that the circuit responded to pulses too short to operate the recorder.

Several modifications of this circuit are possible. If it is desired to use negative pulses, the last 76 may be eliminated. If positive pulses of large power are required, the second 76 may be replaced by a power tube such as the 6L6 or the thyratron type 885. The neon coupling tube may be replaced by any other gas discharge tube, such as the argon type 874. Additional control of the operating characteristics may be obtained through the use of resistances in series with the neon tubes.

The circuit was developed and built in connection with a

program of cosmic-ray research supported by the Carnegie Institution of Washington. Thanks are due T. H. Johnson for helpful discussions.

THE HARD AND SOFT COMPONENT OF COSMIC RADIATION IN TERMS OF A COMMON PRIMARY BACKGROUND.*

BY

W. F. G. SWANN.

The fundamental assumptions which control the view here discussed are the following:

1. There is a single primary background of charged, but nonelectronic type, with energy distribution function $F(E)$ of the form A/E^p.

2. Each primary ray experiences, per unit of path, a number of "events" or collisions, the average number of these per unit of path being β. This number we assume independent of the energy, and we assume the events to be distributed individually and collectively at random in any interval concerned. It results from the latter part of the assumption that the probability of occurrence of n events within the interval βx is $(\beta x)^n e^{-\beta x}/n!$

3. In each of these events the ray loses an amount of energy ϵ, which is the same for all energies. No ray of energy E can, of course, experience more than m losses ϵ, where $m\epsilon = E$.

4. If a ray has energy less than ϵ, it has, nevertheless, the same chance of experiencing an event; but in such an event it loses all of its energy.

5. When a primary ray loses energy, the energy loss goes into secondaries (possibly in part heavy electrons) and some of it gets converted directly or indirectly into ordinary electrons, which then proceed according to the Bethe-Heitler theory, the energy being lost, finally, in ionization and in radiative losses in all cases.

6. The story of the relationship between the number of secondaries per primary and the loss of energy of the primaries

* Reprinted from the *Physical Review*, **54**, 307 (1938).

is controlled by

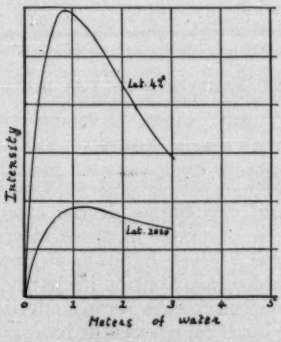
$$\eta dn/dx + \alpha n = dW/dx, \qquad (1)$$

where η is the average energy of all the particles other than primaries, α is the loss per particle per unit of path in ionization and in radiative losses, n is the number of secondaries and higher order particles per primary, and W is the average energy lost by a primary between the top of the homogeneous atmosphere and the depth x.

On the basis of the foregoing assumptions, expressions have been developed for the intensities of the primaries and secondaries—using the latter term to include all the higher order particles. The particular case considered is one where β is less than the energy for entry through the earth's magnetic field at the magnetic equator, but is equal to the energy for entry at some higher magnetic latitude φ, taken as 42° in the example.

For both the primaries and the secondaries, the intensity comes out in the form of a series whose terms correspond to

FIG. 1.



the probabilities of successively larger and larger numbers of events. The earlier terms dominate the story at small values of x, and these terms show a latitude variation. At greater depths, the later terms of the series dominate the situation.

These terms show no latitude effect. Moreover, they correspond to an ever increasing "hardening" of the radiation until finally an absorption coefficient is attained which depends *entirely* upon the distribution function $F(E)$, and is independent of all other elements of the theory. This absorption coefficient varies with x and is given by $\mu = (p - 1)/x$.

We thus realize a condition in which the *latitude effect increases with altitude*, and in which the *measured radiation at any latitude "hardens" with increase of depth.*

The growth of secondaries as determined by (1) results in *a maximum for the intensity* of the secondaries. Moreover, this *maximum occurs at depths which are greater the smaller the latitude.*

Figure 1 shows, for magnetic latitude 42° and for the equator, the intensity of the secondaries plotted against depth for $\beta = 4$ per meter of water, $\epsilon = 6 \times 10^9$ ev., and $p = 3$. These curves are only drawn for illustration and not necessarily with the best choice of constants to fit all the experimental data.

The large value of $\beta\epsilon$ determines a large number of secondaries per primary, which results in the phenomena measured being mainly secondary.

V. 19

BURSTS IN COSMIC RADIATION IN THE EQUATORIAL ZONE.*

BY

S. A. KORFF.

During observations at several stations in the United States and in Peru, 709 bursts in the intensity of cosmic radiation have been observed in three electroscopes of the Millikan-Neher type. These bursts have been classified and analyzed with regard to distribution in energy, in altitude and in latitude. All measurements were made inside an 11 cm. lead shield. Each burst represents the passage of between 200 and 3000 simultaneous rays through the instrument. The observations are summarized in Table 1.

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* Condensed from a paper which was published in full in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*, 43, 227 (1938).

TABLE I.

Summary of all Bursts Observed at Various Altitudes and Latitudes, Classified to Show Distribution in Energy.

Energy of Burst	Number Observed at		
	Kensington	Huancayo	Ticlio
ion-pairs $\times 10^6$			
2.8– 4.3	220	81	
4.3– 5.8	124	62	6
5.8– 7.3	35	5	2
7.3– 8.8	51	23	4
8.8–10.3	31	8	1
10.3–11.8	6	1	3
11.8–13.3	8	5	5
13.3–14.8		1	2
14.8–16.2	6	3	4
16.2–30.2	6	7	
30.2–44.2	2	1	
Total bursts recorded	489	197	23
Instrument-days	383	38	6
Mean barometer in mm.	750	515	426
Elevation in meters	100	3340	4570
Geomagnetic latitude	51°N.	1°S.	0°

A ratio of frequency of occurrence of bursts between Kensington and Huancayo (3340 meters) of 4.05 : 1 is observed in the present work. This is in agreement with a ratio of burst frequencies observed between Chicago and Echo Lake (3250 meters) by Bennett, Brown and Rahmel [1] using a Compton-Bennett model C meter with 12.5 cms. of lead shielding. The Montgomerys [2] found a ratio of frequencies of occurrences of bursts between Swarthmore and Glen Cove (3500 meters) of 14 : 1. However, the lead shield which they used was not comparable in thickness in arrangement with that used in the other measurements cited. Since the bursts are generated in the lead shield, this fact suggests that the differences between the frequency ratios observed are probably due to the different types of shielding used.

Conclusions. We may summarize the properties of the bursts observed:

(1) The number of bursts, R, as a function of their energy, N, in ions, may be expressed approximately by $R = AN^{-3}$ with $A = 30 \times 10^{12}$ ions[2] per day at sea-level.

(2) The distribution in energy of bursts does not vary, within observational error, with altitude.

(3) The distribution in energy of bursts follows, within experimental error, the same form in both the equatorial zone and in geomagnetic latitudes of 40° to 50° north.

(4) The number of bursts increases with altitude approximately as the square of the total ionization measured in the same instrument.

(5) At sea-level, very large bursts represent about one part in 10^4 of the total ionization in the instrument; total bursts above the lower limit of 3×10^6 ions, represent about one part in 10^3.

Acknowledgments. The author wishes to take this opportunity to acknowledge financial support of this project from the Carnegie Institution of Washington. He also wishes to thank Dr. J. A. Fleming and Dr. T. H. Johnson who contributed many helpful criticisms and suggestions. The work in Peru was greatly aided by Dr. G. A. Wagner, Director of the Peruvian Meteorological Service, and by the officers of the Central Railway of Peru who allowed observations to be made in the station at Ticlio.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Studies on the Metabolism and on the Proteolytic Enzymes of the Strict Anaerobes.—J. C. HOOGERHEIDE AND L. WEIL. (Read at the Third International Congress for Microbiology, New York City, September 4, 1939.) Before proteins can be utilized for energy-yielding processes by the spore-forming anaerobes, they are broken down by a proteinase secreted into the culture medium. This proteinase was found to have a pH optimum of 7.0 and could be activated markedly by a combination of − SH compounds and traces of heavy metals. The active group of the enzyme is not, however, an SH-group.

When bacteria were cultivated in the usual culture media, the elaborated proteinase readily attacked all the protein substrates investigated. However, by repeated transplants on simple media, such as casein or gelatin solutions, it was possible to develop two specific proteinases, a casein and a gelatin proteinase. But, by cultivating the casein-trained bacteria on gelatin medium, supplemented by those amino acids missing from gelatin but present in casein, an enzyme was produced which again attacked both proteins. The same was true for gelatin-trained bacteria. These specificities disappeared upon the addition of activator to the enzyme.

When cultivated in the presence of glucose the pH of the culture medium dropped from 7.4 to 5.8 during the growth and the proteinase present in the filtrate of such a culture had a pH optimum of 6.0 instead of 7.0.

The partial breakdown of the proteins by the proteinase in the culture medium is completed by the peptidase systems within the bacterial cells.

Once amino acids are available, they are used by the bacteria in energy yielding processes. Since we are dealing with strict anaerobes no oxidation of amino acids is possible. One source of energy is the fermentation of certain amino acids, such as serine, cysteine, cystine and methionine. Another source of energy is the "Stickland reaction," a reaction between H-donors and H-acceptors.

Of numerous substrates tested, alanine, leucine, isoleucine, amino-valeric acid, valine and pyruvate were found to be very active H-donors when investigated by the Thunberg technique. Active H-acceptors, investigated by Warburg technique, using gaseous H_2 as H donor, were proline, hydroxyproline, glycine, ornithine, arginine and tryptophane. Any combination of H-donor with H-acceptor gave a Stickland reaction.

A third source of energy is intermolecular oxidation-reduction reactions. These are "Stickland reactions" in which two molecules of the same substrate react together, one molecule being oxidized, and the other being reduced. One and the same substrate acts as H-donor as well as H-acceptor in these reactions.

Marked examples of enzymatic adaptation were observed. When the bacteria were cultivated at a somewhat lower pH the pH optima of several dehydrogenases were shifted towards the acid side.

When glucose is present in the medium, bacteria are obtained which are able to utilize actively, glucose and its metabolites, alcohol and hydrogen, contrary to bacteria obtained from a glucose-free medium.

Enzymes apparently are produced or adapted according to the need for them. The enzymatic activity of "resting bacteria" reflects the enzymatic activity in that particular phase of growth, but it changes with the age and with the composition of the culture medium.

Reactions between amino acids (proline, hydroxyproline, glycine, ornithine and tryptophane) and gaseous hydrogen brought about by suspensions of *Clostridium sporogenes* were studied quantitatively and the products formed identified.

The reactions studied were:

proline	$+ H_2 \rightarrow$	δ-amino-valeric acid
hydroxyproline	$+ H_2 \rightarrow$	γ-hydroxy-δ-amino-valeric acid
glycine	$+ H_2 \rightarrow$	NH_3 + acetic acid
ornithine	$+ H_2 \rightarrow$	NH_3 + δ-amino-valeric acid
tryptophane	$+ H_2 \rightarrow$	NH_3 + indolepropionic acid.

Inhibition of Proteinases of Certain Clostridia by Serum. —LOUIS DESPAIN SMITH AND CHARLES H. LINDSLEY.

(*Journal of Bacteriology*, **38**: 221, Sept. *1939*.) Extensive tissue destruction is often found in wounds infected by spore-forming anaerobic bacteria. This destruction can, in general, be ascribed to the action of potent proteolytic enzymes elaborated by these pathogenic organisms. Certain non-pathogenic members of this group, however, produce enzymes which are fully as active as those of the pathogens in hydrolyzing proteins *in vitro*. Some factor other than hydrolytic activity *per se* of the proteolytic enzymes probably plays an important role in the pathogenicity of these micro-organisms.

The proteolytic enzymes of some non-pathogenic members of this group (*Clostridium aerofetidum*, *C. putrificum*, *C. botulinum*, *C. sporogenes*, and a Rough strain of *C. histolyticum*) have been found to be strongly inhibited by fresh, normal, blood serum, when tested on the hydrolysis of gelatin. On the other hand, the pathogenic organisms tested (*C. histolyticum*, *C. oedematis-maligni*, and *C. welchii*) possessed proteolytic enzymes which were inhibited slightly, or not at all, by fresh serum. *C. botulinum*, although usually considered as pathogenic, nevertheless is so only by virtue of its toxin, which must be produced *ex vivo*.

Serum which had stood for a week at room temperature, or for three months in the refrigerator, no longer inhibited the enzymes of the non-pathogenic Clostridia, although it did inhibit trypsin almost as well as did fresh serum. Half saturation with ammonium sulfate also served to destroy the ability to inhibit these bacterial enzymes, although it did not affect the "anti-tryptic" activity.

Consequently, it was thought probable that there were in fresh serum two substances, one inhibiting the enzymes of the non-pathogenic Clostridia, the other inhibiting trypsin. The results of inhibition tests with constituents of serum separated in the electrophoresis apparatus of Tiselius did not support this hypothesis. The albumen fraction seemed to be responsible for the inhibition of both the trypsin and the bacterial enzymes. In addition to the inhibition of the bacterial enzymes by the albumen, there was a slight inhibition by the β globulin. There was no inhibition of trypsin by this serum constituent.

Although the enzymes of the pathogenic Clostridia were not

found to be inhibited by normal serum, they were inhibited by specific immune serum. This specificity was quite sharp, immune serum to *C. histolyticum* inhibiting practically completely the proteolytic enzymes of this organism, but not those of *C. welchii*, *C. sporogenes*, or even of a Rough strain of *C. histolyticum*. Since it precipitated with the globulin fraction of the serum, and was so sharply specific, the inhibiting factor in this immune serum was probably antibody.

Synthesis of Organic Compounds Containing Radioactive Sulfur.—HERBERT K. ALBER. (JOURNAL OF THE FRANKLIN INSTITUTE, **228**: 177, 1939.) Recently R. G. Franklin (*Science*, **89**: 298 (1939); JOURN. FRANKLIN INST., **227**: 722, 724 (1939)) discussed the advantages of using compounds labelled with radioactive sulfur atoms in biochemical investigations, especially in tracing the course of sulfur compounds through the animal body and clarifying the role of certain organs in the highly important problems of sulfur metabolism. By means of a strictly biological method glutathione*, i.e. glutathione containing S^{35}, was synthesized. Yeast was grown in a medium containing MgS^*O_4 as the only source of sulfur, the glutathione* formed being isolated through the cuprous salt.

This *in vivo* synthesis has now been supplemented by the *in vitro* synthesis of organic sulfur compounds* which are intermediates in the preparation of the biologically important sulfanilamide*. This work, because of the small amount of S* available (55 mg.), is an excellent example of a case in which the application of microtechniques is essential to organic synthesis. All operations carried out on a microscale with S* were duplicated by similar syntheses, on the same scale, with ordinary S. This procedure permitted efficient comparisons of physical constants and yields to be made.

S^{35} was obtained by bombarding CCl_4 with neutrons accelerated by the cyclotron of the Biochemical Research Foundation; 1 mg. of purified sulfur containing S^{35} gave 405 counts per minute, all activity measurements being carried out with the Geiger counter mentioned by Franklin.

1-Chloro-4-nitrobenzene was treated with Na_2S and S* in a micro container fitted with a reflux condenser, 100 mg. of crude

material* being obtained (65 per cent. yield). On recrystallization from acetone and glacial acetic acid three fractions of 4,4′-dinitrodiphenyl disulfide* were obtained. Each fraction was tested for its purity, micro melting point on the Kofler hot stage, elementary composition, etc. The second fraction was the most active and gave micro melting points of 140°, 164°, and 178° to 179° C. as compared with the melting points of 134°, 164° to 165°, and 178° to 179° C. given by the inactive compound. It is very probable that three crystal modifications of this compound exist, which may account for the varying melting points reported in the literature.

The radioactive measurements on the 4,4′-dinitrodiphenyl disulfide* were compared with those on the purified S* sample. As is known from studies on other radioactive elements, the ratio between radioactive and ordinary sulfur in the original active sulfur sample remains unchanged in the organic molecule obtained by synthesis. Thus, the ratio of the observed activities was 1 : 1.97 and 1 : 1.01 respectively, which is in good agreement with the calculated ratio of 1 : 2 and 1 : 1 respectively.

The remaining 4,4′-dinitrodiphenyl disulfide* (20 mg.), was treated in 90 per cent. acetic acid with chlorine gas and the resulting crude *p*-nitro-benzenesulfonyl chloride* (99 per cent. yield) was purified by repeated recrystallization from benzene-petroleum ether (55 per cent. yield). The micro melting point was 78.5–79° C. as compared with the literature value of 80° C. The elementary analysis confirmed the identity of the compound.

The radioactive measurements on the *p*-nitrobenzenesulfonyl chloride* were compared with those on the S* and indicated a ratio of 1 : 2.4 instead of the calculated 1 : 2.0. The same results were obtained on comparing the two active sulfur compounds synthesized.

Due to scarcity of material the further steps in the synthesis to sulfanilamide* could not be carried out, but the possibility of synthesizing organic compounds containing S* *in vitro* has been clearly demonstrated even with the small amounts of S* available.

BOOK REVIEWS.

APPLIED ACOUSTICS, by Harry F. Olson and Frank Massa. Second Edition, 494 pages, illustrations, 15 × 22 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1939. Price $5.50.

The outstanding accomplishment of Alexander Graham Bell in 1876 marked the beginning of investigations upon sound systems. Since then the progress of knowledge and achievements has been intermittent although definitely forward as is obvious from the wonders which have been derived from such knowledge. In the more recent past, from these wonders which include the radio and sound motion pictures, there has been given a tremendous impetus to the science of acoustics resulting in a concerted effort to extend the frontiers of practical knowledge in this field to the point of greater application. This book is in its second edition, the first having appeared only five years ago. Development in this period has been so rapid that a new edition is necessary.

The book is a text aimed to furnish essential parts of theory useful for furtherance of a wider and greater knowledge of the subject. The prerequisites necessary for its use are a familiarity with the general principles of physics and of the science of communications, particularly the branches concerned with audio frequencies. The introduction proceeds from this background with a derivation of the fundamental acoustical equations and the second chapter begins the text proper which proceeds through treatments on sound source, sound transmission, and sensations produced by the impact of the waves on the ear drum. Throughout the work the authors have recognized the need of presentation from the standpoint of practice and have used means to procure this end. Thus, in discussing dynamical systems analogical elements are used; there is a section devoted to giving an outline of fundamental acoustical measurements, and electrical apparatus for the acoustical laboratory; there is a continuance of the analogy where the pressure microphone is comparable to the voltmeter, and the velocity microphone to an ammeter in an electrical circuit. Improved loud speakers for various applications are discussed including the basic design principles of Horn Type Loud Speakers.

A chapter on architectural acoustics shows the application of acoustical engineering principles to the quantitative study of the subject, confining itself entirely within its scope and avoiding details of design of auditoriums which rightly is another subject. Reduction of noise is given recognition in a study of noise measurement, pointing out the limitations of the various means. Under the heading, physiological acoustics, information is given regarding the acoustical characteristics and reactions of normal ears in order to provide the reader with the necessary data for passing judgment on the relative merits of apparatus when their physical characteristics are known.

The book is modern in coverage of the subject, in the data it contains, and in method of treatment. It is a useful text for study and the comprehensive subject index enhances its use as a reference.

R. H. OPPERMANN.

V.
19

ENGINEERING OPPORTUNITIES, edited by R. W. Clyne. 397 pages, plates, 15 × 22 cms. New York, D. Appleton-Century Company, 1939. Price $3.00.

The foreword of this book has been written by Dr. Karl T. Compton, President of Massachusetts Institute of Technology. It lays stress on the importance of engineering in the development of this country, and to mankind in general. Not only is it a fitting foreword for what is to follow but it is a statement of such breadth and depth that it holds appeal to old and young, the engineer as well as the layman. To all it is inspirational, creating a desire to read the book and learn more of the diversified opportunities available and how engineering training is classified into divisions to successfully attack humanity's problems and needs. No one who reads this foreword can doubt the value of an engineering training, so realistic and convincing is the story.

The book itself consists of twenty-six chapters, each devoted to describing engineering activities and opportunities of a particular industry and each written by an expert or executive in the industry discussed. Some of the industries covered are aviation, diesel power, glass, petroleum, photography, plastics, and air conditioning. Generally, backgrounds are given, the present position of development, then some idea of trends are outlined, and the economics and value of the industry in its contribution to human welfare are also given attention. The treatments are typical products of engineering training in their coverage, affecting every phase of the activity so that from this feature the reader can gain a glimpse of the broadness of the engineer's mind and training.

The authors are men who have achieved recognition in their field of endeavor, men not too old to recall the problems of youth in the way of choosing a vocation. The book is for the young man in this situation. It is not a recital of easy ways to financial success. It is written on a factual, present-day basis, laying the cards on the table, for the serious minded, ambitious young man. In this sense it is a reference work to all those who are undecided,—a file of opportunities. There are many other industries not covered here, obviously for reasons of limitation of space. Once a file such as this book contains has been started, the trend should be for covering as much as is practicable, the entire field of engineering in addition.

The book has a definite purpose which it adequately meets as far as it goes. It is especially refreshing to note its appearance and contents in these days when to some degree at least, it is usual to hear spoken of the uselessness of a formal education of any kind, the premium on laziness, and technological unemployment.

R. H. OPPERMANN.

AIR CONDITIONING, PRINCIPLES AND PRACTICE, by Burgess H. Jennings and Samuel R. Lewis. First Edition, 467 pages, illustrations, 16 × 23 cms. Scranton, International Textbook Company, 1939. Price $4.00.

Air conditioning is an industry that has leaped forward in a rather short period of time, once it had gotten a start on a broad front. Today it is common to see many installations for year around comfort and the installation and uses in manufacturing processes are multiplying. The industry is still new, holding promise for practicing engineers as well as students. Textbooks for the study of this branch of engineering are not so numerous as in other branches, but the same

care must be used to select a book to fit particular needs. This book leans toward the practical side of the subject. It occupies a position in the span of knowledge, ranging from the strictly theoretical to the actual application, somewhere about the center, being neither too theoretical nor giving too much attention to the minute details of installation and operation. It therefore is a book suitable for those with an understanding of engineering principles.

The treatment is arranged so that a rough division of the book can be made. After a brief statement giving the background of air conditioning, the theoretical basis is covered. This includes the fundamental definitions in heat and thermodynamics, calculations in air and humidity, practical side of air conditioning for human comfort, and heat transfer and transmission coefficients. The second division is predominantly descriptive, having to do with methods of heating—steam, hot water, and warm air. Considerable space is devoted here and the coverage is quite thorough. Fluid flow, air distribution systems, heat transfer elements, boilers, air cleaning and refrigeration are, in order, subsequent subjects. Special mention is made of the control of combustion apparatus used for heating rooms and refrigerating apparatus for cooling rooms. Industrial air conditioning and miscellaneous topics such as air conditioning of railway cars, and noise and its control complete the book.

At the end of chapters there are lists of carefully composed problems for exercise and lists of references for further reading. Many completely solved illustrative problems are given, which are helpful in making the subject matter impressionable. There are also extensive tables and charts of data of a permanent nature. These together with a usable subject index make the book valuable as a reference.

The manner of approach, the logical sequence of topics, the completeness of coverage, and the fact that the treatment goes straight to the kernel of each topic without the use of higher mathematics, these and more features make the book one which should be sought for by all who have need of knowledge of air conditioning engineering.

R. H. OPPERMANN.

FABRE AND MATHEMATICS AND OTHER ESSAYS, by Lao Genevra Simons. 101 pages, 13 × 20 cms. New York, Scripta Mathematica, 1939. Price $1.00.

This little book, number four of the Scripta Mathematica Library, was written with the belief that interest in matters mathematical exists among teachers, scientists and laymen who delve below the surface in the writings of the men in other fields than their own or who are concerned with the survival of subject matter in their own fields. It consists of a collection of four essays. The first is entitled "Fabre and Mathematics" and it gives the facts, for the first time, of the interest of Jean Henri Fabre in mathematics. Fabre it will be recalled was an entomologist and the story here given was written after a study of Fabre's works. The interest of Alexander von Humbolt in mathematics is the subject of the second essay. It discusses evidence of his all embracing interest which was apart from his being a student of the natural and physical sciences.

The third essay is on the influence of French mathematicians at the end of the eighteenth century upon the teaching of mathematics in American colleges. The broadness of this subject makes it particularly absorbing and to many it will be revealing not only in the extent of the influence but the extent of teaching coverage.

The last essay is devoted to Colonial geometry and is divided into a number of stories—a record from each of the several Colonial colleges—which show the ideals of the men connected with each college and the extent to which these ideals may have been reached. Harvard, Yale, Columbia, and the University of Pennsylvania are included. The book makes a pleasant pastime that adds to culture.

R. H. OPPERMANN.

BEYOND YONDER, by Oliver Justin Lee. 169 pages, plates, illustrations, 14 × 20 cms. Boston, Chapman & Grimes. Price $2.50.

It has been said, and probably correctly, that time is the element most important in life. True, time is incidental and usually forgotten because there seems to be an unlimited amount of it. Distance and travel on the other hand, are a constant challenge not easily forgotten, and may therefore be considered as next to time in importance. Dr. Lee, in the first part of this book, calls to mind how distance has gradually become more understood and overcome, its fascination, and how it affects everyday life. In this respect, distance is a factor always to be reckoned with. It has usefulness and it has drawbacks but in the common view it is taken as a matter of course.

In this book, Dr. Lee takes distance from the shelf of the common-place and tells to the reader of average intelligence of the methods used in the determination of distances by the scientist, some of the results obtained, and the potential possibilities which resulted. The book is pleasant to read, involving historical aspects of making measurements which parallel the advance of civilization. Distance is the only subject and it is discussed almost from the infinitesimal to the infinite. The story of how measurements of distances beyond comprehension are arrived at is told in simple, easily understood terms of human experience. There is revealed the care with which scientists use all possible means to check their results and especially their jealous regard for their own confidence in what they are doing. One feature of the book in the relating of scientific methods of measurement is the usual tone assumed by the author in describing or referring to what must have been ingeniousness in selection of method and deducting results. An illustration of this is in the description of the progress made in the measurement of the speed of light. Contrary to what may be expected in effect on the reader, this does not detract from the maintenance of interest. In fact, the manner of presentation appears to be saturated with the personality of the author, that he seems to be speaking as a lecturer with a broad scientific knowledge as well as a broad experience in human activities. He takes liberties gracefully and gets away with them.

The book belongs to that class which is badly needed today, the popularizing of scientific knowledge. It is well done from every angle and deserves wide recognition.

R. H. OPPERMANN.

ELECTRICAL ENGINEERING EXPERIMENTS, THEORY AND PRACTICE, by Henry R. Reed and George F. Corcoran. 500 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $4.50.

Laboratory work as a supplement to class room instruction is recognized generally as a necessity in the teaching of engineering subjects. Too much

emphasis, however, cannot be laid on the many things that laboratory work should accomplish—each of them of as great an import as any other. In the past decade it has been common in many cases to meet young engineers in whom there has been evidence that one or more phases of laboratory work have not been as effective as they should be. Some of this has been in report writing, some in the significance of particular basic experiments, some in observation, and some in method of attack to avoid difficulties. The results of laboratory training in school, if done properly, find many applications in engineering practice generally. Any book covering this subject must therefore be viewed as a tool for several purposes.

This book on electrical engineering experiments is considerably more than a laboratory manual. It covers the entire field of electric power engineering beginning with information and instructions pertaining to laboratory technique, report writing, theory of instruments, etc., and a special section giving brief explanations of the operating principles of the instruments and meters commonly used in electrical engineering laboratories. Then a section on fundamentals is presented covering such matters as tracing circuits, making measurements of resistance by various methods, study of magnetic circuits, etc. With this as a background, other sections are presented on direct current machines, alternating current circuits, transformers, synchronous machines, induction machines, and electronics which considers some of the fundamental properties of tubes but is devoted in the main to electronic applications in the power field. A special feature of the work is the inclusion of sufficient information on results which might be obtained from the experimentally determined data and the descriptive matter of the apparatus and instruments used which is often supplemented by instruction on how and what to observe on examination of them. The book is self contained, no other reference work being required. From the standpoint of the instructor it is flexible; each experiment is complete in itself so that a choice of experiments is available to suit different purposes and situations. Including the subject index, there are 500 pages to the book. This gives an indication of the multitude of experiments recorded.

There is much to recommend this book for use in schools of engineering, and aside from this many practicing engineers will find it helpful in the way of a reference to subjects not often encountered, as well as to the newer methods and equipment.

R. H. OPPERMANN.

IONS, ELECTRONS AND IONIZING RADIATIONS, by James Arnold Crowther. Seventh Edition, 348 pages, plates, illustrations, 14 × 23 cms. New York, Longmans, Green & Co., 1939. Price $4.00.

The subjects covered by this book have been investigated and developed to a tremendous extent in the past three decades, and the results of this work are very evident both in theory and in practical ways. Such revelations of great magnitude have provided inspiration for further work so that it has been practically continuous for some years. The subjects are typical illustrations of the almost constant need for texts in order to keep up-to-date. This book is the seventh edition, which bears evidence of a close following of progress.

For the benefit of those who are unfamiliar with previous editions the chapter

headings are as follows: the passage of a current through an ionized gas, the properties of the gaseous ions, the charge of an ion, ionization by collision, the phenomena of the discharge tube, cathode rays and positive rays, emission of electricity by hot bodies, photo-electricity, X-rays, the α rays, the β and γ radiations, cosmic radiation, the physics of the nucleus, the structure of the atom, radio-active changes, and radium and its products.

The method of presentation is what may be termed descriptive instruction, with equal weight on each word. It is therefore not a coverage of an elementary nature, considerable training in atomic physics as well as mathematics being a necessary prerequisite. For those who are qualified, the book represents an exhaustive effort to bring between two covers material pertinent to the subjects, which has been somewhat scattered, this material presented in an informative descriptive style. In this the work excels.

The flavor of a textbook, in the usual sense, is lost in many portions of the treatment. This is undoubtedly due to the added material which was necessary from time to time to reflect the modern state of the subject. A set of miscellaneous examples toward the end of the book is a strict reminder of its text nature. They give indication of careful formulation and the answers are provided. A subject index completes the treatment.

R. H. OPPERMANN.

TEXTBOOK OF ORGANIC CHEMISTRY, by E. Wertheim. 830 pages, illustrations, plates, 16 × 24 cms. Philadelphia, P. Blakiston's Son & Co., Inc. Price $4.00.

This volume of 830 pages seems like a large order for the beginner in organic chemistry but its careful layout and interesting and practical viewpoint make it much less difficult for study than the organic chemistry textbook of twenty years ago.

Some points which strike the reviewer as worthy of note are the following:

1. Drawings, tables and charts are numerous.
2. References given at the end of each chapter are very thorough.
3. Discussions are given of numerous useful methods and theories not usually found in a book of this type (e.g., calculation of heats of combustion of alcohols by the Kharasch method, p. 109; Free Radicals, p. 391, etc.).
4. Detailed mention of properties of specific compounds is put in tabular form in appendices, where it is more convenient to find and use.

And speaking of appendices, these are better than those found in most textbooks, including flow sheets of industrial processes, a list of textbooks, a glossary of terms, a chronological table, a table of derivations of organic compounds, besides a table of melting points, boiling points and solubility data.

This book is well printed, on excellent paper, and should have a long and useful life.

GEORGE S. GARDNER.

USES AND APPLICATIONS OF CHEMICALS AND RELATED MATERIALS, by Thomas C. Gregory. 665 pages, 16 × 24 cms. New York, Reinhold Publishing Corporation. Price $10.00.

To quote the author, this book "contains surveys on the uses, potential applications and sales possibilities of 5167 chemicals and related materials." It

is a chemical dictionary of a type that is most useful to the purchasing agent, the salesman and business man who handles chemicals. It is not a book which would find much use in a chemical laboratory.

As an example of the scope of the book we might select at random one entry, "phenol." The following data are given: Synonyms, foreign equivalents, and uses in various industries together with patent numbers.

The book is well indexed and well printed and bound. It might be valuable in the office and library as a general reference work.

GEORGE S. GARDNER.

COMPLEX VARIABLE AND OPERATIONAL CALCULUS WITH TECHNICAL APPLICATIONS, by N. W. McLachlan. 355 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $6.50.

Many practicing engineers, trained in the old school, have had considerable difficulty when encountered with problems requiring the use of the differential or integral calculus. Indeed, in years gone by the calculus in many instances was regarded as somewhat of a mystery and the rules were memorized only to the extent necessary for the solution of meaningless equations. Today, with more complex knowledge necessary, the calculus is recognized as indispensable and educational systems have risen to meet the need. The engineering student takes the calculus at least in some degree of rigor in his stride. This opens up a field in which there is a balance, on the one hand not too much theory as would be the case were the subject to be taken by the pure mathematician, and on the other hand just sufficient theoretical background so that the engineer would know what he is doing in solving a problem by the use of the calculus. The author of this book attempts to strike this medium.

The book is divided into three parts. The first is of an introductory nature on the complex variable. It is expected that readers be familiar with complex numbers and de Moivre theorem. Starting with a treatment on the functions of a complex variable, it proceeds through integration and differentiation, the calculus of residues, the Bromwich contour, and differentiation and integration under the integral sign. The procedure goes up to the point necessary for an understanding of the operational method. It is based upon well known classical works, suitable and rigorous enough for technologists. There are examples introduced containing a technical bias. Needless to say, this part must be understood thoroughly before proceeding further.

In part two the so-called operational calculus is developed using complex integration as treated in part one. The operational formulae are based upon both parts of the Mellin inversion theorem and the treatment differs from the experimental nature of that of Heaviside. Many theorems given here can be employed in pure mathematics to obtain new formulae or to establish relationships, but such applications are avoided since their inclusion would undoubtedly unbalance the theme.

Practical applications of the subjects so far discussed are covered in part three of the book. A large number of problems taken from many branches of applied science are worked out in detail. They include absorption and evaporation of moisture, aeroplane stability, annealing of steel rods, automobile brakes,

cable telegraphy and line transmission, electrical circuits, electrical wave filters, loud speakers, torsional oscillations, transmission of heat in slabs, etc. Then there are examples to be worked out by the reader.

What is called a fourth part of the book contains appendices and list of references. It serves the purpose of making it possible to avoid interpolated explanations of cognate points in the text as reference is made to it throughout the book.

The book as a text has value to the student who is prepared to follow it and to the engineer who has need of such knowledge. There is an accurate conception of what is necessary in the practical application of the subject.

R. H. OPPERMANN.

PROCEEDINGS OF THE FIFTH INTERNATIONAL CONGRESS FOR APPLIED MECHANICS, held at Harvard University and the Massachusetts Institute of Technology, Cambridge, Massachusetts, September 12–16, 1938. 748 pages, illustrations, 23 × 29 cms. New York, John Wiley & Sons, Inc., 1939.

Organized in 1922, the International Congress for Applied Mechanics held its first meeting in 1924, the second in 1926, and subsequently every four years thereafter. The contents of this volume constitute the papers presented before the fifth meeting in Cambridge, Mass., in 1938. The meeting was opened by an address of welcome by President Karl T. Compton of M.I.T. in which he explains some of the difficulties in the field of Applied Mechanics as the reason for the congress. Thereafter there are some 129 papers in the volume divided into the subjects of mechanics of solids, elasticity and properties of materials, fluid mechanics, and dynamics. An appendix contains addresses at the dedication of the Wright Brothers Wind Tunnel. The great majority of the papers are in English while some are in German and French. All are complete with illustrations. They are of especial interest because they represent the thought of men of learning and distinction from various countries of the world on the subjects covered.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 650, The Aerodynamic Characteristics of Six Full-Scale Propellers Having Different Airfoil Sections, by David Biermann and Edwin P. Hartman. 34 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

Wind-tunnel tests are reported of six 3-blade 10-foot propellers operated in front of a liquid-cooled engine nacelle. The propellers were identical except for blade airfoil sections, which were: Clark Y, R.A.F.6, N.A.C.A. 4400, N.A.C.A. 2400–34, N.A.C.A. 2R$_5$00, and N.A.C.A. 6400. The range of blade angles investigated extended from 15° to 40° for all propellers except the Clark Y, for which it extended to 45°.

The results showed that the range in maximum efficiency between the highest and the lowest values was about 3 per cent. The highest efficiencies were for the low-camber sections. An analysis of the results indicated that blade sections for controllable propellers which are not limited in diameter should be selected chiefly on a basis of minimum drag (which affects maximum efficiency) inasmuch as the maximum lift coefficients had only a small effect on the take-off characteristics

within the range investigated because stalling, in general, did not occur. Sections for fixed-pitch propellers should be selected on a basis of both minimum drag and maximum lift, particularly for blade-angle settings of 20° and over, because the take-off thrust power increased with maximum lift for the higher blade angles.

Report No. 655, The Knocking Characteristics of Fuels in Relation to Maximum Permissible Performance of Aircraft Engines, by A. M. Rothrock and Arnold E. Biermann. 22 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

An analysis is presented of the relationship of various engine factors to knock or pre-ignition in an aircraft engine. From this analysis and from the available experimental data, a method of evaluating the knocking characteristics of the fuel in an aircraft-engine cylinder is suggested. Because the method is based on the physical factors controlling knock, the knocking-characteristic curve for each fuel expresses the relative maximum permissible engine performance obtainable from the fuel. Curves are presented showing the manner in which the knocking-characteristic curve can be used to predict the relationship between compression ratio and maximum permissible indicated mean effective pressure, minimum permissible specific fuel consumption, and maximum permissible peak pressure for any one fuel. Additional curves show that the knocking-characteristic curves permit a rational choice to be made between two or more fuels or permit the fuel to be selected that most satisfactorily meets the given engine requirements. The suggested method of determining the knocking characteristics is compared with the octane-number scale. Throughout the discussion, the susceptibility of the fuels to the temperature conditions within the engine is emphasized.

Report No. 656, The Column Strength of Two Extruded Aluminum-Alloy H-Sections, by William R. Osgood and Marshall Holt. 24 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

Extruded aluminum-alloy members of various cross sections are used in aircraft as compression members either singly or as stiffeners for aluminum-alloy sheet. In order to design such members, it is necessary to know their column strength or, in the case of stiffeners, the value of the double modulus, which is best obtained for practical purposes from column tests.

Column tests made on two extruded H-sections are described and column formulas and formulas for the ratio of the double modulus to Young's modulus, based on the tests, are given.

Report No. 657, The Influence of Directed Air Flow on Combustion in a Spark-Ignition Engine, by A. M. Rothrock and R. C. Spencer. 14 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

The air movement within the cylinder of the N.A.C.A. combustion apparatus was regulated by using shrouded inlet valves and by fairing the inlet passage. Rates of combustion were determined at different inlet-air velocities with the

engine speed maintained constant and at different engine speeds with the inlet-air velocity maintained approximately constant.

The rate of combustion increased when the engine speed was doubled without changing the inlet-air velocity; the observed increase was about the same as the increase in the rate of combustion obtained by doubling the inlet-air velocity without changing the engine speed.

Certain types of directed air movement gave great improvement in the reproducibility of the explosions from cycle to cycle, provided that other variables were controlled.

Directing the inlet air past the injection valve during injection increased the rate of burning.

Report No. 659, Effect of Service Stresses on Impact Resistance, X-Ray Diffraction Patterns, and Microstructure of 25S Aluminum Alloy, by J. A. Kies and G. W. Quick. 22 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

A great number of tests were made to determine the effect of service stresses on the impact resistance, the X-ray diffraction patterns, and the microstructure of 25S aluminum alloy. Many of the specimens were taken from actual propeller blades and others were cut from $\frac{13}{16}$-inch rod furnished by the Aluminum Company of America.

The average impact resistances were found to be unchanged even after 288,000 cycles in a 0- to 33,400-pound-per-square-inch range that exceeded the fatigue limit and the original proof stress of the material. The X-ray diffraction patterns were unchanged as regards any indication of structural change resulting from the fatigue stressing of the alloy. Two structural conditions known as slip-plane precipitation and veining were observed. The service stresses were not responsible for the slip-plane precipitation and the endurance limit was not reduced by it. Veining could be made to disappear and reappear by alternate solution heat treatment and age hardening.

Report No. 660, Experimental Investigation of the Momentum Method for Determining Profile Drag, by Harry J. Goett. 7 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

An experimental investigation has been conducted in the full-scale tunnel to determine the accuracy of the Jones and the Betz equations for computing profile drag from total- and static-pressure surveys in the wake of wings. Surveys were made behind 6- by 36-foot airfoils of the N.A.C.A. 0009, 0012, and 0018 sections at zero lift and behind the N.A.C.A. 0012 airfoil at positive lifts. The surveys were made at various spanwise positions and at distances behind the airfoil ranging from 0.05c to 3.00c.

The reduction of the test data by either the Jones or the Betz equation gave profile-drag coefficients agreeing within 2 per cent. with those obtained by force tests at zero lift. The variation of the profile drag determined at stations from 0.05c to 3.00c behind the trailing edge was small and the error resulting from

the induced field of a lifting airfoil did not exceed 2.5 per cent. at a C_L of 1.0 and a spanwise station of 0.78 $b/2$.

Report No. 662, Design of N.A.C.A. Cowlings for Radial Air-Cooled Engines, by George W. Stickle. 11 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

The information on the propeller-cowling-nacelle combinations, presented in Technical Reports Nos. 592, 593, and 596 and in Technical Note No. 620, is applied to the practical design of N.A.C.A. cowlings. The main emphasis is placed on the method of obtaining the dimensions of the cowling; consequently, the physical functioning of each part of the cowling is treated very briefly. A practical method of designing cowlings and some examples are presented.

Report No. 663, The Effect of Continuous Weathering on Light Metal Alloys Used in Aircraft, by Willard Mutchler. 27 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 15 cents.

An investigation of the corrosion of light metal alloys used in aircraft was begun at the National Bureau of Standards in 1925 and has for its purpose the study of the causes of corrosion in aluminum-rich and magnesium-rich alloys together with the development of methods for its prevention.

The results, obtained in an extensive series of laboratory and weather-exposure tests, reveal the relative durability of a number of commercially available materials and the extent to which the application of various surface coatings of oxide alone and with paint coatings afforded additional protection. The paper may be considered as a supplement to N.A.C.A. Report No. 490.

Report No. 666, Aircraft Rate-of-Climb Indicators, by Daniel P. Johnson. 10 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1939. Price 10 cents.

The theory of the rate-of-climb indicator is developed in a form adapted for application to the instrument in its present-day form. Compensations for altitude, temperature, and rate of change of temperature are discussed from the designer's standpoint on the basis of this theory. Certain dynamic effects, including instrument lag, and the use of the rate-of-climb indicator as a statoscope are also considered. Modern instruments are described. A laboratory test procedure is outlined and test results are given.

PUBLICATIONS RECEIVED.

A Text Book on Light, by A. W. Barton. 426 pages, plates, illustrations, 15 × 22 cms. New York, Longmans, Green and Co. Price $3.00.

Vapor Charts and Special Tables for Turbine Calculations, by Frank O. Ellenwood and Charles O. Mackey. 43 pages, plates, 22 × 29 cms. New York, John Wiley & Sons, Inc., 1939. Price $2.50.

Physics, by Erich Hausmann and Edgar P. Slack. Second Edition, 756 pages, illustrations, 15 × 23 cms. New York, D. Van Nostrand Company, Inc. Price $4.00.

The Raman Effect and its Chemical Applications, by James H. Hibben. 544 pages, illustrations, tables, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1939. Price $11.00.

Rubber Red Book, Directory of the Rubber Industry, 1939 Edition. 420 pages, 15 × 23 cms. New York, The Rubber Age. Price $5.00.

Steam, Air, and Gas Power, by William H. Severns and Howard E. Degler. Third Edition, 511 pages, illustrations, tables, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $4.00.

The Psychology of Physics, by Blamey Stevens. 278 pages, illustrations, 15 × 23 cms. Manchester, Sherratt & Hughes. Price 7s. 6d.

Unification of Gravitation—Magnetism and the Internal Structure of Bodies. A Contribution of the Absolute-Relative Theory to the Unification of Natural Phenomena, by Franklin J. Matchette. 31 pages, 18 × 26 cms. New York, Author, 1939. Price 50 cents.

National Advisory Committee for Aeronautics. Technical Notes: No. 707, Compression-Ignition Engine Performance with Undoped and Doped Fuel Oils and Alcohol Mixtures, by Charles S. Moore and Hampton H. Foster. 31 pages, illustrations. No. 723, Adhesion of Ice in Its Relation to the De-Icing of Airplanes, by A. M. Rothrock and R. F. Selden. 13 pages, illustrations. No. 724, The Effects of Surface Waviness and of Rib Stitching on Wing Drag, by Manley J. Hood. 18 pages, illustrations. No. 725, Tank Tests to Determine the Effects of the Chine Flare of a Flying-Boat Hull N.A.C.A. Model Series 62 and 69, by Joe W. Bell and Roland E. Olson. 38 pages, illustrations. 4 pamphlets, 20 × 26 cms. Washington, Committee, 1939.

CURRENT TOPICS.

Rankine Memorial Movement.—It is well within the facts to say that every single machine, bridge, steamship, or dam that has been scientifically designed in the last sixty years has owed something of value to WILLIAM JOHN MACQUORN RANKINE. This Scottish engineer and physicist was born in Edinburgh on July 5, 1820, and completed his education in its university. He was trained as an engineer under Sir J. B. Macneill, working chiefly on surveys, harbors, and railroads, and was appointed in 1855 to the chair of civil engineering in Glasgow. Rankine was the earliest of the three founders of the modern science of thermodynamics on the bases laid by Sadi Carnot and J. P. Joule respectively, and the author of the first formal treatise on the subject; 150 scientific papers are credited to him in the Royal Society's Catalogue. The United States, of course, is heavily indebted to this great man, for his work has contributed much toward the marvelous industrial development in this country. It is fitting therefore that the Intercollegiate Rankine Memorial Movement has been started. The purpose is to collect from the student body of every engineering college in America a total sum of $15,000 to erect a memorial at the University of Glasgow. In the promotion of the plan various advantageous aspects can be seen aside from its prime purpose. They include an increase in world prestige for each of the nearly two hundred engineering colleges in America, the cultural effect in a humanistic enterprise, and the results that will flow from demonstrating the efficacy of coöperative effort. Suggestions for student participation include the offering of a prize for the best biographical article in the college magazine and the award of a bronze bust to the college subscribing the largest amount to the fund.

R. H. O.

World Growing Warmer, Say Russians.—(*Heating and Ventilating*, Vol. 36, No. 5.) The findings of Soviet explorers aboard the ice-breaker Syedoff, now drifting near the North Pole, together with earlier observations by other investigators, have caused Soviet scientists to conclude that the Arctic region and, indeed, the whole world is growing warmer. This conclusion was voiced in reports published separately by PROF. N. N. ZUPOFF of the Meteorological Institute of the Northern Sea Route Administration, and PROF. L.

BERG, corresponding member of the Soviet Academy of Sciences. They are cautious about deducing causes or prophesying the duration of the change of climate. Professor Berg recalls that the ice age 3,000 to 5,000 years ago was followed by an epoch in which the average summer temperature was higher than now. Both scientists mention the Gulf Stream as a possible cause of the rising temperatures but agree that this can at most be contributory—that other factors are causing a rise in the temperature of the Gulf Stream, which carries warmer water northward. They give considerable credence to the theory that climatic change may be due to increased heat from the sun either because solar radiation has been intensified or because resistance by the earth's atmosphere to the sunrays has been reduced.

R. H. O.

Believe Rayon Near Limit of Expansion.—Nearly 2 billion pounds of rayon were produced in the world in 1938. This was roughly the equivalent of about 4.5 million bales of cotton. Twenty years ago the production of rayon was only 33 million pounds, or the equivalent of about 80 thousand bales of cotton. Will rayon production continue to increase at this rapid rate? Cotton specialists of the Bureau of Agricultural Economics think that it will not. They believe that production of rayon and other synthetic fibers will increase, but less rapidly than in recent years. They believe that rayon is approaching a limit of expansion into those fields for which it is suitable. Despite the inroads of rayon into such important uses for cotton as dress fabrics, underwear, and hosiery, world cotton consumption increased during the post-war period from 17.2 million bales in 1920–21 to nearly 28 million in 1938. Rayon has become a bigger competitor of cotton in some countries than in others. In Germany, rayon has been substituted for cotton under government decrees. In Japan and Italy, and possibly in a few other countries, a similar situation exists, says the Bureau. With the exception of rayon, synthetic textile materials have not displaced a significant quantity of cotton, whatever their potentialities may be.

R. H. O.

Tung Oil Research is New Federal Project.—Water resistance is the outstanding quality of tung oil that gives it particular value as a drying oil in paints, varnishes, and enamels. The Chinese discovered this property of tung oil centuries ago, since which time they have been using it to preserve their wood carvings and as an annual coating for their wooden ships and bridges and even to

waterproof their masonry. In commenting on the Department of Agriculture's research program in the two new tung oil laboratories to be opened soon at Bogalusa, La., and Gainesville, Fla., Dr. Henry G. Knight, Chief of the Bureau of Chemistry and Soils, said that increased recovery of oil would be given especial attention in these laboratories. Dr. Knight pointed out that although the Chinese have had hundreds of years of experience with tung oil production, yet their methods of extracting the oil are still rather primitive. He said that experimentation will be carried on looking toward the extraction of tung oil with solvents instead of relying altogether on pressing to squeeze the oil from the nuts, as is done in China. It is hoped that higher yields of oil may be obtained by the extraction method which has been used with considerable success in the soybean industry.

R. H. O.

New Intermetallic Compound.—P. M. McKENNA. (*Industrial and Engineering Chemistry, News Edition*, Vol. 17, No. 14.) Search for a hard tool metal capable of machining steels, hardenable Monel metal, and corrosion-resistant chromium and nickel alloys, with speed and economy, has resulted in the discovery of a new intermetallic compound corresponding to the formula $WTiC_2$ or more correctly, $W_2Ti_2C_4$. This substance is obtained by heating tungsten, titanium, and carbon in pure graphite crucibles in a bath of nickel to a temperature above 2000 deg. for a prolonged period, whereupon crystals of tungsten-titanium carbide are formed. Upon cooling, the crystalline substance is separated from the nickel menstruum by digestion, first with aqua regia and other reagents, and finally with hydrofluoric acid in platinum dishes. The process is protected by U. S. Patents 2,113,354–5–6. The main use of this compound is in a series of hard alloys, marketed under the name "Kinnametal," which vary in hardness of 89 to 91 Rockwell "A" and have strengths of 200,000 to 300,000 pounds per square inch in transverse rupture tests. This is harder than the hardest tool steel, which has a maximum hardness of about 83 Rockwell "A." These alloys are produced in vacuum furnaces by processes of powder metallurgy, the $WTiC_2$ crystals being pulverized with cobalt, tungsten, and carbon under exacting conditions, then pressed into a variety of shapes.

R. H. O.

Pellucid Tough.—(*Industrial Bulletin of Arthur D. Little, Inc.*, No. 149.) A glass that can be heated in a blast lamp till it glows,

and then immediately plunged into ice water without breaking, has recently been developed by American technologists. The new product, capable of mass production, consists of 96 per cent silica (quartz sand). It is comparable in most respects except cost to fused quartz (100 per cent. silica). Since fused quartz articles are manufactured by an expensive process not adapted to mass production methods, involving the fusion of selected quartz crystals, first in vacuum and then under pressure in an electric furnace, their uses are highly restricted. The Corning Glass Works therefore has bent its efforts toward developing a less expensive product with properties approximately similar to those of fused quartz. This they have now succeeded in doing. Briefly, the process consists of forming an article from a modified Pyrex glass melt; heat-treating to separate the constituents of the glass into two phases; dissolving out one phase containing most of the flux; and then fusing the remainder to give a clear, transparent product, free from striations and bubbles, and undistorted by the considerable shrinkage which occurs as the glass fills the voids left by leaching. Like fused quartz, the chemical and thermal resistance of this new material is outstanding. Its coefficient of linear expansion is only some 40 per cent. greater than that of fused quartz. That of the best previous glass, by contrast, is 470 per cent. greater; of ordinary window glass, some 1300 per cent. greater. It may, moreover, be used at temperatures up to 1000 deg. C., nearly twice the previous limit for glass and only 100 deg. less than that for fused quartz. Because of the exceptional electrical insulating properties of materials containing as much silica as this new glass, it may become a leader in the field of high voltage insulators, and may upset present spark plug design.

R. H. O.

Playing With the Paraffines.—In the rapidly growing organic chemical industry based on hydrocarbons from petroleum, all too little attention has been given to one of the oldest and purest of all sources of the paraffines—Pennsylvania crude oil. Lately however, some interesting developments on the higher paraffines are under way, notably in the refinery of the Kendall Refining Co. S. D. KIRKPATRICK in *Chemical and Metallurgical Engineering*, Vol. 46, No. 7, describes several new products and their preparation which are the outcome of these operations and which may prove of value to many chemical process industries. The first of these products consists of a series of high-boiling naphthas, distilled from Pennsylvania kerosene or gas oils. They cover, in general the range from C_{10} to C_{20} and are available in sharply cut fractions boiling over a

temperature range as narrow as 10 deg. C. Their great advantage lies in their extreme uniformity. The second series of new products being made by Kendall consists of dewaxed and deresined mineral oils of extremely high viscosity and high-viscosity resinous materials obtained from the operation of its new propane dewaxing and deresining plant. Again, like the naphthas, these products are free from sulphur and are of extremely uniform composition and properties. They are being used on a considerable scale in compounding special rubber and plastic compositions. Other applications will doubtless develop as their unusual characteristics become known. The work has largely grown out of that done at Pennsylvania State College by Fenske and his associates to meet changes in technical developments in the oil industry elsewhere than in Pennsylvania.

R. H. O.

Wear Phenomena in Fluid Lubrication.—The first part of experimental studies on non-fluid lubrication is discussed by S. KYROPOULOS in *Refiner and Natural Gasoline Manufacturer*, Vol. 18, No. 7. By means of a simple apparatus and microscopic observation, the dependency of surface wear and polish on the characteristics of the lubricant was studied. An electrical effect was found to be responsible for wear in contrast to polish in the presence of solid (e.g., wear) particles. The lubricating efficiency of an oil may be increased by excluding the electric effect and its resulting effects. This may be done by direct electrical connection of the surfaces and/or by discharging the surfaces and particles by means of imparting electrical conductivity to the oil. Polar substances, added to the oil, perform this discharge directly or indirectly. Their effect is in low concentrations proportional to the resulting conductivity of the oil. The magnitude of the electrical field strengths is such that it may lead to the building up of field currents at the peaks which will tend to promote seizure. The electrical effect originates in fluid lubrication and leads to local non-fluid lubrication in small clearances.

R. H. O.

Utilizing Heat From the Sun.—In large regions lying in the low latitudes, desert conditions prevail. Day after day the sun glares down, occasionally dimmed a little by cirrus clouds, or perhaps by a few heaping cumuli. In such regions 80 per cent. or even more of the hours of daylight would be useful for furnishing a great amount of solar heating. This is the statement of C. G. ABBOT in a paper in *Electrical Engineering*, Vol. 58, No. 7. With regard to the devices for transforming this energy for use, he states that the com-

mercial development of aluminum products and the common use of vacuum devices have contributed to the extent of overcoming the difficulty of costly apparatus. It is now possible to purchase the so-called " Alcoa " in thin sheets, which readily take the curvature of a suitable cradle form without previous shaping. This material reflects over 80 per cent. of solar radiation, and may be used for years without dimming. As the loss of heat in the boiler at the focus of a solar-radiation appliance is the great obstacle to be provided against, the possibility of making cheap glass jackets enclosing high vacua like thermos bottles is the other great improvement. The author describes various kinds of apparatus. Of special interest is that of a cooker for food in which the use of water was dispensed with in favor of " Arochlor " a nearly black liquid product of the Monsanto Chemical Co. This was made almost completely absorptive of sun rays by adding a small amount of lampblack in suspension. It does not boil below 350 deg. C. and evaporates scarcely at all at lower temperatures and is used directly in a vacuum jacketed glass focus tube. Also, a flash solar boiler for power is described. With the high efficiency and great simplicity of the arrangement Mr. Abbot computes that power can be had from the sun at not exceeding 0.5 cent per horsepower hour and still give a good return on the investment.

R. H. O.

Dry Heat Storage.—(*Heating and Ventilating*, Vol. 36, No. 8.) Increased interest is being shown in the commercial possibilities of dry heat storage in which small lumps of magnetite are contained in refractory tubes and heated by electricity. This method is being employed in the heating of buildings and for drying. According to GASTON ROUX, writing in *Revue Generale de l'Electricite*, the first industrial plant of this type was installed at the Chedde (Haute Savoie) works of the Cie. de Produits Chimiques et Electro-Metallurgiques Alais, Froges at Camargue, in 1936. This heater, directly connected to a 6,000 volt supply, absorbed 100 kw. and stored approximately 4,000,000 B.T.U. in 6 tons of broken magnetite, heated to between 900° and 1100° F. Satisfactory results were obtained in the drying of potassium chlorates and other salts, and a second high voltage heater was installed at Asnieres for heating offices and rooms for engineers of the Nord-Lumiere company. At Asnieres, about 4,158,000 B.T.U. are stored during a charging period of 14 hours, and the stored heat is utilized over the twenty-four hours. For use in small houses and flats, thermal storages operating on the same principle are made by compressing powdered magnetite in steel

tubes lined with insulating material and surrounded by cast-iron blocks which contribute to the storage of heat. Magnetite has been chosen as the best material for this form of heat storage after extensive trials with many minerals.

R. H. O.

Shadow of Ship Fires Torpedo.—{*Commerce and Industry*, Vol. XIX, No. 10–11.) A torpedo that would utilize the shadow of the enemy ship to blow up that vessel has been designed by JOHN HAYS HAMMOND, JR., of Gloucester, Mass. This is revealed in a patent (No. 2,164,916) awarded by the U. S. Patent Office to Mr. Hammond. The torpedo is photoelectrically operated. It travels deep under the surface of the water, turns suddenly upward when it comes in the shadow of the ship, and explodes under the ship's bottom. In the top of the torpedo is a photoelectric cell. This is connected to an electrical system which controls the course and the explosion of the torpedo. When the torpedo is fired, natural daylight filtering through the water is focused on the photoelectric cell and the solenoid mechanism which controls the explosion is de-energized. However, as soon as the torpedo passes under the bottom of the ship, the light to the photoelectric cell is cut off by the shadow of the ship. This is "noted" by the photoelectric cell. The mechanism controlling the course of the torpedo automatically changes so as to direct the torpedo upwardly against the bottom. At the same time the solenoid is energized to explode the torpedo under the ship. To prevent premature explosions, as when the torpedo may pass under some floating debris, there is included a delay action unit which makes it necessary for the photoelectric cell to be cut off from light for an appreciable period of time before the torpedo will explode.

R. H. O.